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Cincinnati, Ohio
May 16-17, 1984

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The proceedings are a compilation of speaker's papers and panel session reports. The speaker's topics covered: 1) Plumbing Materials: Plumbing Materials on Water Quality, and 3) Impact of Plastic Pipe and Fittings on Water Quality.

Panel session reports are also presented on four topics: 1) Joining Alternatives for Cooper Pipe, 2) Metal Pipe and Fitting Alternatives for Plumbing, 3) Plastic Pipe and Fittings, and 4) Regulatory and Compliance Aspects. These reports summarize the discussions that were held during the panel sessions including the conclusions and recommendations made by each group.

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Cincinnati, Ohio May 16-17, 1984

Co-sponsored by

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PREFACE

The National Interim Primary Drinking Water Regulations define a Maximum Contaminant Level (MCL) as "the maximum permissible level of a contaminant in water which is delivered to the free-flowing outlet of the ultimate user of a public water system, except in the case of turbidity where the maximum permissible level is measured at the point of entry to the distribution system." With this definition, the Federal regulations clearly recognize that the quality of drinking water can be affected by its distribution lines and that it is the responsibility of the water purveyor to consider these problems in providing water to its customers.

Traditionally, water utilities have taken control measures to prevent or correct problems associated with water distribution mains. Studies and reports during the past several years have clearly illustrated that distribution problems are not limited only to distribution mains, but are also associated with laterals and service lines as well as the interior plumbing systems in dwellings and buildings. Some of these problems, such as lead leaching from lead service lines and plumbing, have been common knowledge for years. Other problems, such as the migration of gasoline and other petroleum distillates through plastic pipe, have been more recently identified.

On May 16-17, 1984, the Office of Drinking Water and the Drinking Water Research Division of the U.S. Environmental Protection Agency cosponsored a seminar to review drinking-water problems related to plumbing materials (including those used in service lines) and to identify solutions for dealing with these problems. In attendance were approximately 150 people representing government, manufacturers, trade associations, consultants, and public interest organizations. During the first day, speakers addressed three general topics: (1) the use, application, and availability of plumbing materials (metallic and plastic); (2) the impact of these materials on water quality; and (3) solutions to plumbing problems related to water quality.

On the second day, four concurrent panel sessions were held for all attendees to share their knowledge and to express their viewpoints on the information presented. These panel sessions proved to be very worthwhile. A wide variety of opinions and viewpoints were expressed on the four panel topics: (1) joining alternatives for copper pipe; (2) metal pipe and fitting alternatives for plumbing; (3) plastic pipe and fittings; and (4) regulatory and compliance aspects.

The first section of these Proceedings includes the papers given by the speakers on plumbing material applications, problems, and solutions. The latter part of this section includes as a highlight "A Review of European Developments in the Use of Plumbing Materials," presented by Ivo Wagner of the Engler-Bunte Institute, Karlsruhe, West Germany. The second section contains the reports of the panel sessions prepared by the panel chairman. Although these reports vary somewhat in format, each contains a summary of the opinions, conclusions, and recommendations of the panel. The Proceedings conclude with a summary of the conclusions and recommendations of the panel meetings and a synopsis of the seminar presentations. This seminar was timely and successfully presented many views on the complex issue of plumbing materials and water quality.

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ABSTRACT

The seminar on Plumbing Materials and Water Quality was held at the Andrew Breidenbach Environmental Research Center in Cincinnati, Ohio on May 16 and 17, 1984. The purpose of the seminar was to review drinking water problems related to plumbing materials and to identify alternative solutions for dealing with these problems.

These proceedings are a compilation of speaker's papers and panel session reports. The speaker's topics covered: 1) Plumbing Materials: Extent of Use, Application and Availability, 2) Impact of Metallic Plumbing Materials on Water Quality, and 3) Impact of Plastic Pipe and Fittings on Water Quality.

Panel session reports are also presented on four topics: 1) Joining Alternatives for Copper Pipe, 2) Metal Pipe and Fitting Alternatives for Plumbing, 3) Plastic Pipe and Fittings, and 4) Regulatory and Compliance Aspects. These reports summarize the discussions that were held during the panel sessions including the conclusions and recommendations made by each group.

The document concludes with a general summary of conclusions and recommendations of the entire seminar.

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METAL PIPING AND JOINING MATERIALS AND FITTINGS

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Copper is the oldest engineering metal, and has been in continuous use for plumbing since the time of the Pharaohs. Copper sheet rolled into tubular form to conduct water has been found in excavated Egyptian tombs. Over the centuries water has been conducted to the consumer through stone aqueducts, hollow wooden logs, iron and steel pipe, and today's highly engineered copper tubular products.

The Copper Development Association analyzes the 25 largest application areas for copper and its alloys. Arranged in order of rank, based on 1983 data, plumbing and heating is the most important use for copper, followed by building wiring. These two major building construction applications accounted for 27 percent of U.S. copper and copper alloy shipments last year. This is the first time plumbing and heating has led the list.

Each year in the United States, well over half a billion linear feet of copper water tube are installed in water service and distribution systems. This is equivalent to about 125,000 miles of hot and cold water systems. Since 1946, when such statistics began to be gathered in the United States, 17 billion feet of copper tube have been installed in water service and distribution systems for buildings. That is more than 3 million miles.

But what do these copper shipments mean? The market can be measured by usage intensity. Is copper usage in plumbing growing or declining compared to building construction in general? To find out, we need to compare copper plumbing tube usage to building construction activity.

Housing starts seem to be the best measure of total building activity. Plumbing is predominantly a residential market in the United States, and using square feet of total construction makes the index too diffuse. The two curves in Figure 1 compare housing starts and copper plumbing tube shipments over the last 12 years on an index basis, with 1972 set equal to 100. There is no doubt that copper plumbing tube consumption

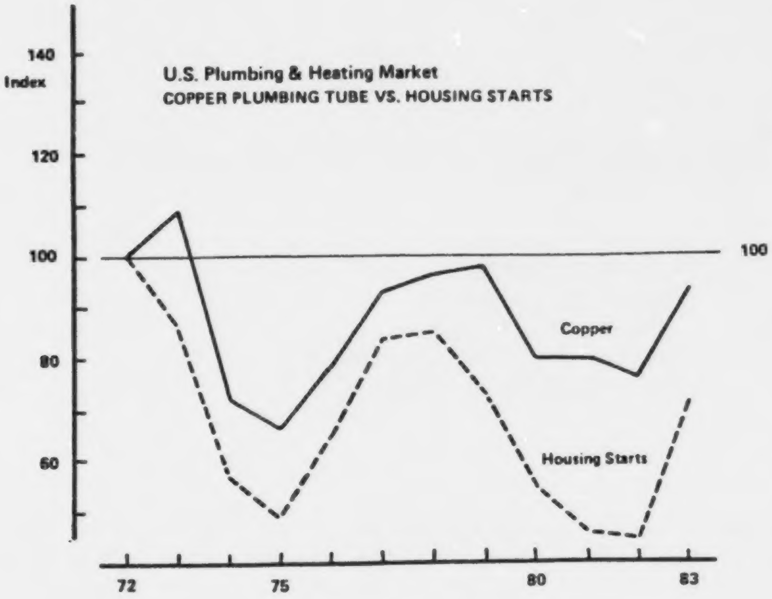

FIGURE 1

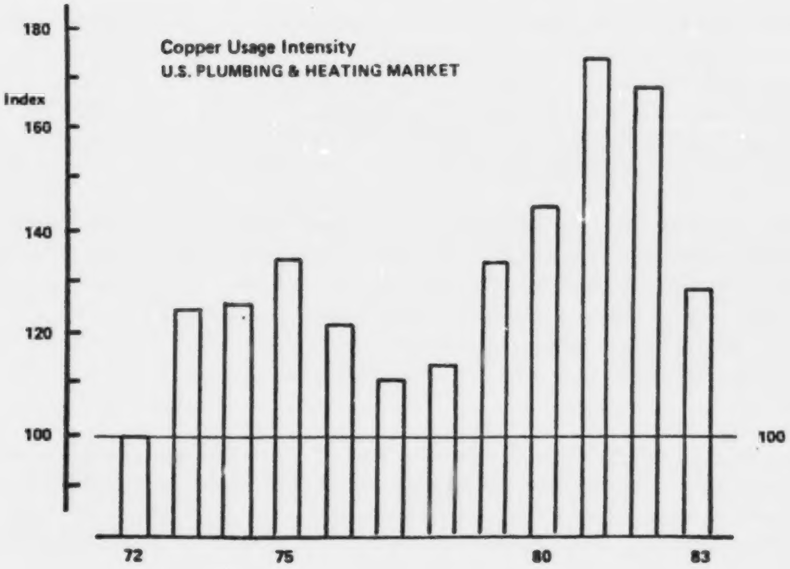

FIGURE 2

follows housing starts. To convert these data to usage intensity, we can divide the index for copper shipments by the index for housing starts.

This gives an intensity index -- usage per housing start, in effect (Figure 2). The result highlights something that was difficult to appreciate when it was happening in 1974 and 75 and in 1980, 1981, and 1982. It shows that plumbing and heating has been a very healthy usage for copper over the last 10 years, outperforming housing starts. How can this be explained?

The major factors include the introduction of copper fire sprinkler and solar heating systems, which brought copper technology into new applications in the market in the mid-1970's. There has been increased usage of large diameter copper tube starting in 1981. Large diameter tube has, in the past few years, penetrated plumbing applications held by steel, largely in commercial and industrial buildings. Finally, there seems to be a trend, as in the 1960s, for more plumbing per dwelling unit.

Through the late 1960s and the 1970s, increasing copper usage intensity in the plumbing and heating market trended downward. This measure reached a low point in 1977. It reflected the well-known shift to thinner wall tube in domestic plumbing systems. This was plumbing progress that improved copper's usage efficiency -- more plumbing per pound of copper. Since 1977, however, the downward trend has been overpowered by increasing use of larger diameter and thus heavier weight copper tube. Fire sprinklers and solar heating use larger diameters than domestic water systems. Large diameter tube usage is increasing in commercial and industrial water supply systems.

To appreciate the relationship between the end-use market and the reliability of the plumbing tube product, understanding of the manufacture and quality assurance operations is needed. Copper metal is derived from two sources, the mine and recycled scrap, each accounting for about 50 percent of total U.S. production.

In fact, copper is the most recycleable of all the engineering metals, with the use of recycled scrap averaging between 44 and 54 percent of total production over the past decade; the figure was 53 percent last year. The reason: recycled copper is identical chemically and metallurgically with new refined copper.

Copper cathode from the refinery is blended with recycled No. 1 scrap from either wire and cable mills or brass mills, then remelted to produce the copper billet. These billets are held in the cast shop until the production quality control laboratory has completed its quality analysis and releases the billet for conversion into tubular products in the mill.

Massive equipment is involved in the conversion of the billet into tubular products. Following inspection, each billet is heated to the proper temperature prior to insertion into the extrusion press for conversion into a tube shell. The ram is inserted into the billet cavity and pressure applied to the heated billet, moving it to the die surface. The billet is then pierced prior to operation of the main ram. The main ram then pushes the hot billet through the die with the center punch of the ram acting as the internal core around which the tube forms as it is extruded through the die. Surface defects are prevented from being extruded into the tube shell by proper ram and extrusion chamber clearance.

The tube shell is further reduced to final size through a series of diameter/wall thickness reductions on bull blocks or draw benches. Drawing lubricants used by seamless tube manufacturers are lead-free, water-soluble, lightweight mineral oils. The nature of tube size reduction is such that the internal surface is wiped clean of any residue by a floating plug and tool steel die.

These tubular products are produced either as copper or copper alloys by the seamless or welded manufacturing methods. A total of 12 ASTM specifications have been developed to cover these commercial products. Ninety-eight percent of water tube is manufactured according to ASTM Standard Specification B88.

ASTM B88 describes three types of copper tube: Types K, L and M. Each of these tube types is a series of standard diameter sizes with specified wall thicknesses. Type K is the thickest wall, Type M the thinnest, L intermediate. A lightweight distribution tube is also available. About three quarters of all copper water tube installed is either half-inch or three-quarter-inch in nominal size.

Prior to packaging and shipment, all tube must undergo product inspection to ensure that the finished tube meets quality assurance requirements. This is accomplished by the eddy-current, nondestructive inspection operation, which is not subject to operator fatigue, so exacting acceptance criteria are continually maintained on the production line. Immediately after the eddy-current inspection station, the name of the manufacturer and tube type are marked on the tube surface by inking and incise impressions. This identifies the tube as to source, type, and specification and assists the plumbing inspector in verifying that it meets code requirements.

Solder joint plumbing fittings are produced according to the same exacting manufacturing standards as tube (ANSI B16.18 or B16.22). They are made in a wide variety of shapes and sizes, including couplings, T's, elbows, and reducing and special fittings. All quality assurance operations applied to tube apply here as well.

Up to now, my remarks have been directed to the role of copper tube in use, its production and quality assurance. Let me now comment on why copper has achieved such a remarkable level of acceptance by the building community.

Copper is the dominant material used in potable water systems. Its combination of corrosion resistance in hot and cold systems and ease of installation is unmatched by any other plumbing material in use today. Service experience in general indicates that copper plumbing tube will outlast the building in which it is installed. Further, the combination of nontoxicity and nonflammability properties makes it the leading choice.

As with all materials, copper can be attacked by some highly aggressive environments, and problems arise occasionally with certain well waters, with very soft waters high in carbon dioxide, and in systems where the water flow velocity in excess of about 5 fps causes erosion.

In a modern waterworks, the chemist in charge not only prescribes treatments to make the water conform to health regulations, such as to free it of pathogenic organisms, but for well waters he must also make arrangements, if necessary, for chemical treatments designed to reduce the corrosiveness of the water. The water purveyor may not fully recognize this responsibility or the economic advantages of providing a water suitably adjusted chemically to reduce its corrosiveness. All of this is directly relevant to one of the topics of this conference: lead pickup from soldered plumbing systems.

Potable waters are developed from a variety of sources, including lakes, rivers, streams, and wells. Reservoirs are used to store water where there is seasonal or annual variation. Surface waters tend to be saturated with air. Waters taken directly from wells may be low in oxygen but may contain much higher levels of carbon dioxide and minerals than surface supplies. Unlike surface waters, well waters are usually free of algae and organic matter.

Waters are routinely treated for biological purity, but in addition, each water source has to be examined to determine whether some form of correction or treatment is necessary to control its corrosiveness. Often, all that is required is pH adjustment. The form of corrective treatment may be to control scaling or to reduce corrosion. Treatments with other objectives must be evaluated for the possible effect on the corrosiveness of the water. For example, water must meet the new EPA limit of one turbidity unit. Flocculation, the treatment to clarify turbid water, often uses a coagulant such as alum to remove suspended matter. Water treatment can also be used to protect consumers from lead pickup by aggressive acid waters.

Suitable treatments are routine in modern waterworks. Where the water purveyor continuously controls the character of the water fed to the mains, he not only ensures optimum corrosion performance of his own supply system but also greatly reduces costly customer-related water problems. Unfortunately, smaller water purveyors in many cases do not provide corrective treatments, either from lack of understanding of the need or from lack of the proper facilities.

Corrosion and metal pickup, including lead pickup from poorly made solder joints, can be prevented in domestic plumbing systems by refraining from the use of aggressive waters or with effective water treatment of either surface or well waters. This has been the case for over 50 years of highly serviceable use of copper tube and fittings for water distribution systems. Examples of successful treatments that have been introduced include simple aeration, the addition of caustic soda, soda ash or lime. Neutralizing filters have also been used in private dwellings. Up to now, these treatments have been aimed primarily at protecting consumers against pitting and general corrosion, but the same principles apply for protection against lead pickup by acid soft waters from poorly made joints. Consider a few case histories that demonstrate the effectiveness of this approach to consumer protection.

At one location in California, simple aeration of the water reduced the free carbon dioxide content from over 20 mg/l to about 10 mg/l and was adequate to alleviate a corrosion problem in the system served. This was done simply by spraying the well water into the water supplier's large storage tank via a large-diameter perforated pipe at the top of the tank reservoir.

In another area treatment with caustic soda (NaOH) was effective in neutralizing the free carbon dioxide in a pitting water serving a particular housing development, causing the pitting attack to cease. When treatment was stopped, the pitting resumed. When a nonpitting water was finally introduced into the system, pitting stopped altogether. In this case, the treatment consisted of the addition of caustic soda to raise the pH and eliminate the free carbon dioxide.

Another example of the effectiveness of water treatment is in the community of Fort Shawnee, Ohio. Here, an isolated housing development of about 100 residences and condominiums is served by a single well-water source. About five years ago, an epidemic of cold water pitting in these homes was brought to our attention. Of the 100 or so dwellings, 16 suddenly experienced 28 pitting perforations in their cold water distribution systems.

Equipment was installed in the waterworks to inject sodium carbonate (Na_2CO_3 H_2O) into the water to raise the pH and neutralize the free carbon dioxide. Since the treatment began there has not been a single additional corrosion failure within the buildings served by the treated water.

In Suffolk County, New York, a water supply system with about 150 well fields (two to three wells per field) has for many years treated the combined output of more than 350 wells by injecting a slurry of lime (CaO) into the supply. The remaining wells are treated with caustic soda. When properly treated, this raises the pH to about 7.5, reducing the CO_2 to less than 5 mg/l, and eliminates the copper water tube corrosion problems on the system almost completely.

A housing development in San Bernardino County, California, started to experience corrosion approximately 1.5 years after the residences were initially occupied. Because of the reluctance of the water utility to introduce the needed treatment, neutralizing filters were introduced by the developer at each residence. These units contained a bed of dolomite ($CaCO_3$ MgO) which functions by reacting with and removing the free carbon dioxide from the water with concurrent increase of pH of the water.

The excess hardness (Ca and Mg) is then reduced by passing the first-stage treated water through a second tank containing an ion exchange resin.

To summarize, copper tube and fittings have been the dominant accepted plumbing products in the United States for several decades, providing trouble-free service to residential and commercial users.

It would be foolhardy to claim that corrosion has not occurred in copper plumbing systems, but our studies show this situation to be highly localized and preventable. Other than for faulty design and poor workmanship, corrosion and metal pickup are invariably associated with aggressive water compositions. Successful treatments utilized by local water utilities have corrected the water chemistry problems. This has resulted in trouble-free plumbing systems for the consumer and high quality drinking water. The same approach can protect consumers from lead pickup from poorly made solder joints in those few — really extremely few and isolated — potable water systems that are aggressive as a result of acidity and lack of hardness.

PLASTIC PIPING AND JOINING MATERIALS

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INTRODUCTION

First use of thermoplastics piping for conveying potable water dates back to the early 1950s. Since then, thermoplastics piping has grown to become a most widely used material for a broad range of applications including water distribution, sewerage, drainage, plumbing, gas distribution, industrial uses, and power and communications ducting. Experience has established that thermoplastics piping very often provides the most economical and satisfactory long-term solution.

The broad acceptance of thermoplastics piping not only evidences the inherent capabilities and versatility of these materials, but it also reflects the attention that has been given, from the start of the plastics industry, to the development of a standardization system that suitably addresses all the major performance requirements, including preservation of water quality. The key element of the standardization system covering thermoplastics piping for potable water applications is that it scrutinizes each and every commercial formulation for two most important characteristics: no adverse effect to water quality, and long-term strength under end-use conditions.

AVAILABLE MATERIALS FOR PLUMBING APPLICATIONS

The major thermoplastic materials used for potable water transport and plumbing applications include polyvinyl chloride (PVC), chlorinated polyvinyl chloride (CPVC), polyethylene (PE), polybutylene (PB), and acrylonitrile-butadiene-styrene (ABS). As indicated by Table 1, all of these materials are used to manufacture pressure piping. However, some materials and products are used preferentially over others depending on the application, and Table 1 also shows current market preferences.

TABLE 1

THERMOPLASTIC PIPING PRODUCTS
FOR POTABLE WATER APPLICATIONS

KEY: X - Most Frequently Used
O - Less Frequently Used

MATERIAL	PRODUCT STANDARD	TITLE (ABBREVIATED) OF STANDARD	SIZE RANGE (INCHES)	MAINS		SERVICES	YARD PIPING	HOT/COLD DISTRIBUTING
				RURAL	MUNICIPAL			
PVC	AWWA C 900	PVC Pressure Pipe for Water	4 to 12	O	X			
	ASTM D 2241	PVC Plastic Pipe SDR/PR	1/2 to 24	X	O	O	X	
	ASTM D 2466	PVC Fittings, Sch. 40	1/2 to 8	X	O	O	X	
	ASTM D 2672	PVC Pipe, Belled End	1/2 to 8	X	O	O	X	
	ASTM D 1785	PVC Plastic Pipe, Sch. 40-80	1/2 to 12	O	O	O	O	
	ASTM D 2740	PVC Plastic Tubing	1/2 to 1-1/4			O		
PE	AWWA D 901	PE Pipe & Tubing for Services	1/2 to 3			X	O	
	ASTM D 2239	PE Plastic Pipe, SDR/PR	1/2 to 6	O	O	X	X	
	ASTM D 2609	Plastic Insert Fittings	1/2 to 4	O		X	X	
	ASTM D 2737	PE Plastic Tubing	1/2 to 2			X	O	
	ASTM D 2683	PE Fittings, Socket Type	1/2 to 4			O	O	
	ASTM D 3281	PE Fittings, Butt Type	1/2 to 10	O	O	O	O	
	ASTM D 3035	PE Pipe, SDR/PR, OD Controlled	1/2 to 6	O	O	O	O	
	ASTM F 714	PE Pipe, SDR/PR, Large Diam.	3 to 63	O	O			
PB	AWWA C 902	PB Pipe & Tubing for Services	1/2 to 3			X	O	
	ASTM D 2662	PB Pipe, SDR/PR	1/2 to 6			X	O	
	ASTM D 2666	PB Tubing	1/2 to 2			X	O	
	ASTM D 3000	PB Pipe SDR/PR, OD Controlled	1/2 to 6			O	O	
	ASTM D 3309	PB Hot/Cold Water Systems	1/2 to 2				X	
CPVC	ASTM D 2846	CPVC Hot/Cold Water Systems	1/2 to 2					X
	ASTM F 441	CPVC Pipe, Sch. 40-80	1/2 to 12					O
	ASTM F 442	CPVC Pipe, SDR/PR	1/2 to 12					O
	ASTM F 438	CPVC Fittings, Sch. 40	1/2 to 6					O
ABS	ASTM D 2282	ABS Pipe, SDR/PR	1/2 to 12	O		O		
	ASTM D 468	ABS Fittings, Sch. 40	1/2 to 8	O		O		

The major products used for the various non-pressure plumbing applications are presented in Table 2. Pressure and non-pressure piping made from ABS, PVC, and CPVC can be jointed by solvent cementing. Table 3 identifies the standard cements. The polyolefins, PE and PB, are most often joined by mechanical systems, primarily insert, compression, and flare. They can also be joined by heat fusion, but this technique is usually used for larger pipe and by major users such as gas distribution companies.

A very popular technique for joining buried PVC pipe is the elastomeric gasket. Almost all PVC American Water Works Association (AWWA) C-900 water distribution pipe as well as American Society for Testing and Materials (ASTM) D 3034 sewer pipe is manufactured with integral bells with gaskets, into which the spigot end may be pushed for easy joining in the field. The various available joining methods are summarized in Table 4.

Estimates of the approximate market share held by the various thermoplastic materials in water distribution and plumbing applications are given in Table 5. These are *very rough* estimates because accurate statistics on actual shipments to different market sectors presently are not collected by government or industry. The estimates presented in Table 5 have been developed by consolidating the best judgment of a number of knowledgeable people in the industry.

ATTRIBUTES OF PLASTIC PIPING

When evaluating the capacities and limitations of any piping material, it is important to examine its performance in an operational system rather than to compare certain individual properties with those offered by alternate materials. Individual properties of materials, such as shown in Table 6, are measured under conditions that do not sufficiently approximate those encountered in actual use. Furthermore, each material can have its own particular problems, *all* of which need to be recognized and resolved if the material is to be used successfully in a working system. With traditional materials, the resolution of many of these problems has come about very gradually through years of experience. With the newer thermoplastics materials, the evolution to mature engineering materials has been accelerated through an emphasis on the technological assessment of potential performance limitations, particularly long-term durability. That this evolution is proceeding most successfully is indicated by the quite successful application history and the excellent acceptance of plastics for a broad range of applications.

ADVANTAGES

The principal advantages of thermoplastics piping are as follows:

Immunity to "corrosion". Plastics do not rust, pit, or corrode in the sense that metals do. Being nonconductors, they are not susceptible to galvanic or electrochemical effects and, therefore, are unaffected by

TABLE 2

THERMOPLASTIC PIPING PRODUCTS
FOR NON-PRESSURE PLUMBING APPLICATIONS

KEY: X - Most Frequently Used
O - Less Frequently Used

MATERIAL	PRODUCT STANDARD	TITLE (ABBREVIATED) OF STANDARD	SIZE RANGE (INCHES)	BUILDING DRAINAGE & VENT		BLDG. SEWER	BLDG. STORM SEWER	SUBSOIL DRAIN
				ABOVE GROUND	BELOW GROUND			
PVC	ASTM D 2665	PVC DWV Pipe & Fittings	1-1/4 to 6	X	X	X	X	O
	ASTM D 2949	3-In. PVC Thin Wall DWV Pipe	3	X	X	O		
	ASTM D 3311	DWV Fitting Patterns	1-1/4 to 6	X	X			
	ASTM D 2729	PVC Drain Pipe & Fittings	2 to 6			O	O	X
	ASTM D 3033	PVC Sewer Pipe & Fittings, PSP	4 to 15			O	O	O
	ASTM D 3034	PVC Sewer Pipe & Fittings, PSM	4 to 15			X	X	O
ABS	ASTM D 2661	ABS DWV Pipe & Fittings	1-1/4 to 6	X	X	X	X	O
	ASTM F 628	ABS Foam Core DWV	1-1/4 to 6	X	X	X	X	O
	ASTM D 2751	ABS Sewer Pipe & Fittings	1 to 6			X	O	O
PE	ASTM F 405	PE Corrugated Tubing & Fittings	3 to 8					X

TABLE 3

SOLVENT CEMENTS FOR THERMOPLASTIC PIPING

MATERIAL	PRODUCT STANDARD	TITLE (ABBREVIATED) OF STANDARD
ABS	ASTM D 2235	Solvent Cements for ABS Piping
PVC	ASTM D 2564	Solvents for PVC
ABS/PVC	ASTM D 3138	Solvent Cements for ABS/PVC Transitions
CPVC	ASTM F 493	Solvent Cements for CPVC Piping

TABLE 4

JOINING METHODS

	THERMOPLASTIC PIPE				
METHOD	ABS	PVC	CPVC	PE	PB
Solvent Cementing	O	O	O	-	-
Heat Fusion	-	-	-	O	O
Threading (Sch. 80 only)	O	O	O	O	-
Insert	-	-	-	O	O
Mechanical Compression	O	O	O	O	O
Flaring	-	-	-	O	O
Elastomeric Seal	O	O	O	O	O

TABLE 5

ESTIMATED MARKET SHARES OF THERMOPLASTIC PIPING IN WATER DISTRIBUTION AND PLUMBING APPLICATIONS

PRESSURE PIPE

MATERIAL	MAINS		SERVICES	YARD PIPING	HOT/COLD DISTRIBUTING
	RURAL	MUNICIPAL			
PVC	80	25	10	20	
PE	1		30	60	
PB			10		6
CPVC					9
ABS					
Others	19	75	50	20	85
	100	100	100	100	100

NON-PRESSURE PIPE (FOR HOME CONSTRUCTION ONLY)*

MATERIAL	BUILDING DRAINAGE & VENT		BLDG. SEWER	BLDG. STORM SEWER	DRAIN
	ABOVE GROUND	BELOW GROUND			
PVC	60	60	70	70	40
ABS	20	20	10	10	
PE (Corrugated)					60
Others	20	20	20	20	
	100	100	100	100	100

*Market shares for plastics are substantially less for other types of construction.

TABLE 6

TYPICAL PHYSICAL PROPERTIES OF MAJOR THERMOPLASTIC PIPING MATERIALS

PROPERTY AT 75° F	ASTM TEST NO.	ABS	PVC	CPVC	PE	PB
Specific Gravity	D-792	1.08	1.40	1.54	0.95	0.92
Tensile Strength psi (10^3)	D-638	7.0	8.0	8.0	3.2	4.2
Tensile Modulus psi (10^5)	D-638	3.4	4.1	4.2	1.3	0.55
Impact Strength, Izod ft-lb/inch notch	D-256	4	1	1.5	|10	|10
Coeff. of Linear Expansion in/in-°F (10^5)	D-696	6.0	3.0	3.5	9.0	7.2
Thermal Conductivity Btu-in/hr-ft-°F	D-177	1.35	1.1	1.0	3.2	1.5
Specific Heat Btu/lb-°F	-	0.34	0.25	0.20	0.55	0.45
Approx. Operating Limit[1]						
°F, nonpressure	-	180	150	210	160	210
°F, pressure	-	160	130	180	140	180

[1] Exact operating limit will vary for each particular commercial plastic material. Effect of environment should be considered.

acids, bases, salt, "corrosive" waters, or "hot" soils. They can be, however, susceptible to other forms of degradation, such as direct chemical attack and solvation.

Nonconductivity of electricity. This capacity reduces the problem of electrolytic corrosion of connected metallic piping.

Light weight; ease of use. These features simplify handling and installation with attendant cost savings and worker accident reduction. Their light weight also reduces dead-load forces on the structure.

Hydraulically smooth surfaces. Results in most efficient flow and minimal accumulation of deposits.

Elimination of brazing and soldering. During construction, fire hazards and work accident hazards from torches used for brazing and soldering of metal piping are eliminated.

Low stiffness. Allows for the accommodation of deformations with minimal stress development. For certain materials, i.e., PE and PB, stiffness is low enough to allow for coiling of smaller diameter pipe. Decreases sound transmission.

Ductility. The capacity of thermoplastics to undergo significant permanent deformation without fracture allows them to shed off, by means of localized deformation, concentrated earth and other loading.

Durability. Properly selected and installed thermoplastics piping can provide very high reliability and long service life.

Energy efficiency. Significantly less energy is required to manufacture a given length of plastic pipe than that needed to produce most metal pipes. For example, it has been estimated that the energy requirements for the manufacture of 2-inch, 160-pound-per-square-inch (psi) PE pipe are 60 percent of those for the same size copper pipe.

LIMITATIONS

The principal limitations of thermoplastics piping include:

Time, temperature, and environment sensitivity. All the engineering properties, including strength, stiffness, and strain at failure, are dependent on load, duration of loading, temperature, and environment. Furthermore, the sensitivity can vary not only from one type of plastic to another (i.e., PVC and PE), but also can significantly differ within the same material type depending on the exact choice of polymer and additives as well as on processing conditions. These limitations must be recognized in product design and standardization, particularly when limiting conditions, such as higher temperature, are likely to be encountered in actual service.

High coefficient of expansion/contraction. The thermal expansion/contraction of unrestrained plastics can be from 6 to 10 times greater than with metals. This requires greater attention to support spacing in horizontal runs. However, because of their significantly lower stiffness, expansion/contraction can often be restrained without the development of excess forces.

Light weight. Because of its low mass, thermoplastic piping offers little acoustical dampening to airborne sound. The light weight, in combination with low stiffness, can also result in greater movement of piping from hydraulic loads. This necessitates that more attention be given to proper pipe restraint in above-ground installations.

Electrical insulator. Grounding of electrical appliances and electrical circuits must be accomplished via a separate conductor and ground spike.

Combustibility. Control of the spread of fire, and toxic gases from plumbing chases, or walls containing thermoplastic materials, may require special attention to installation details, particularly when penetrating fire-rated building components. However, modern fire technology indicates that such attention to effects of wall penetration is appropriate to all piping materials.

DESCRIPTION OF THERMOPLASTIC PIPE MATERIALS

"Plastic" is as indefinite a term as "metal." First, plastics consist of two basic groups, thermosetting and thermoplastics, which are both used in the manufacture of piping. Thermoplastics, as the name implies, soften upon the application of heat and reharden upon cooling. This characteristic enables them to be readily formed into a wide variety of different shapes. Thermosetting plastics, on the other hand, form permanent shapes when cured by the application of heat or a "curing" chemical.

Secondly, among the thermoplastics the characteristics and properties depend both on the specific chemical composition of the base resin and on the kind and amounts of additives included in the commercial composition. For example, it is possible to formulate mixtures of polyvinyl chloride (PVC) resins plus appropriate additives to yield "vinyl" compositions that range from a clear, soft, and pliable product (such as is used to produce laboratory tubing and upholstery) to a rigid and strong material (such as for pressure pipe). For these reasons, standardization of plastic pipe materials not only classifies the base resin, but also defines the composition by a combination of specific end-property requirements that take into account possible property variability contributed by formulation additives of a plastics composition. Additives for plastics can consist of antioxidants, stabilizers, colorants, ultraviolet protective screens, lubricants, property modifiers (i.e., impact and stiffness), and fillers.

In the case of thermoplastic pipe materials intended for pressure piping and potable water service, the current material classification system requires that each commercial composition used for such product be evaluated to: (1) demonstrate that no deleterious substance will leach from the plastic into the potable water; and (2) establish the material's long-term strength under conditions of service. These requirements recognize that, because of variabilities in polymer and additives, plastics compositions cannot be adequately defined solely on the basis of the "short-term" physical property requirements that are part of ASTM material standards. These requirements alone are not a source of sufficient assurance that potable water quality will not be adversely affected and that the material has adequate long-term strength capacity for the intended service. Consequently, for a plastic material to be acceptable for potable water pressure piping, it must satisfy, under requirements in effect since the early 1960s, two additional criteria: (1) it must be approved for contact with potable water based on requirements not less strict than those in National Sanitation Foundation (NSF) Standard No. 14; and (2) it must have a recommended hydrostatic design stress (HDS) based on long-term pressure testing. The NSF requirements and programs are described in detail in a companion presentation by Dr. Nina McClelland of NSF.

The recommended HDS for individual commercial formulations is established from long-term pressure testing data on the basis of ASTM D 2837, "Standard Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials." The Hydrostatic Stress Board of the Plastics Pipe Institute (PPI) has been issuing since the mid-1960s recommendations of HDS for commercial grades of thermoplastic piping materials. These recommendations, which are based on the methods of D 2837 and the additional requirements given in PPI TR-3, "Policies and Procedures for Developing Recommended Hydrostatic Design Stresses for Thermoplastic Pipe Materials," appear in the regularly updated report PPI TR-4, "Recommended Hydrostatic Strengths and Design Stresses for Thermoplastic Pipe and Fittings Compounds." Nearly all U.S. thermoplastic pipe pressure standards reference the PPI recommendations. NSF policy requires such recommendation for each approved pressure piping material.

The distinctive characteristics of the principal thermoplastic piping materials are as follows:

Polyvinyl Chloride (PVC). PVC piping is made from compositions containing no plasticizers and only minimal quantities of other ingredients. To differentiate these materials from flexible, or plasticized, PVCs (from which are made such items as upholstery, luggage, and laboratory tubing), they have been labeled rigid PVCs. Rigid PVCs used for piping range from a Type I to Type III as identified by a previous classification system that is still in use. In this system the Type designations are supplemented by Grade designations (i.e., Grade I or II) which further define the material's properties. Type I materials, from which most pressure and non-pressure pipe is made, have been formulated to provide optimum strength as well as chemical and temperature resistance. Type II materials are those formulated with modifiers that improve impact strength but that also somewhat reduce, depending on modifer type and quantity, the aforementioned properties of Type I materials. There is little call for Type II pipe, as the impact strength of the stronger Type I pipe is more than adequate for most uses. Type III materials contain some inert fillers which tend to increase stiffness concomitant with some lowering of both tensile and impact strength and chemical resistance. Some non-pressure PVC piping, such as that used for conduit, sewerage, and drainage, is made from Type III PVCs.

The currently used classification system for rigid PVC materials for piping and other applications is described in ASTM D 1784, "Standard Specification for Rigid Polyvinyl Chloride and Chlorinated Polyvinyl Chloride Compounds." This specification categorizes PVC materials by numbered cells that designate value ranges for the following properties: impact resistance (toughness), tensile strength, modulus of elasticity (rigidity), deflection temperature (temperature resistance), and chemical resistance. The following table cross-references the designation of the principal PVC materials from the older to the newer classifications system.

CELL CLASSIFICATION SYSTEM OF ASTM D 1784 MINIMUM CELL CLASS	OLDER SYSTEM	
	TYPE AND GRADE	DESIGNATION
12454-B	Type I, Grade I	PVC 11
12454-C	Type I, Grade II	PVC 12
14333-D	Type II, Grade I	PVC 21
13233	Type III, Grade I	PVC 31

The designation of PVC materials that have been formulated for pressure piping also includes a code indicating their maximum recommended HDS for water at 73° F as determined from long-term pressure testing. For example: PVC 1120 is a Type I, Grade I PVC with a maximum HDS of 2,000 psi for water at 73° F; and PVC 2110 is a Type II, Grade I PVC with a 1,000 psi HDS. The last two digits in the number code identify, in hundreds of psi, the material's maximum recommended design stress. Table 7 presents all the PVC designations used in pressure piping.

The combination of good long-term strength with higher stiffness explains why PVC has become the principal plastic pipe material for both pressure and non-pressure applications. Major uses include: water mains; water services; irrigation; drain, waste, and vent (DWV) pipe; sewerage and drainage; well casing; electric conduit; and power and communications ducts. A much broader range of fittings, valves, and appurtenances of all types is available in PVC than in any other plastic.

Chlorinated Polyvinyl Chloride (CPVC). As implied by its name, chlorinated polyvinyl chloride is a chemical modification of PVC. CPVC has properties very similar to PVC, but the extra chlorine in its structure extends its temperature limitation by about 50° F (28° C), to nearly 200° F (93° C) for pressure uses and about 210° F (99° C) for non-pressure applications. ASTM D 1784, the rigid PVC materials specification, also covers CPVC which it classifies as Class 23477-B. By the older designation system, it is known as Type IV, Grade I PVC. CPVC's for pressure pipe are designated CPVC 4120 (i.e., Type IV, Grade I CPVC with a maximum recommended hydrostatic design stress of 200 pounds per square inch (lb/in^2) for water at 73.4° F. At 180° F (82° C) the maximum recommended hydrostatic design stress for CPVC is 500 lb/in^2 (3.4 MPa).

Principal applications for CPVC are for hot or cold water piping and for many industrial uses that take advantage of its higher temperature capabilities and superior chemical resistance.

Polyethylene (PE). Polyethylene is the best-known member of the polyolefin group (plastics that are formed by the polymerization of straight-chain hydrocarbons, known as olefins), which includes ethylene, propylene, and butylene. Polyethylene plastics are tough and flexible even at subfreezing temperatures. They are generally formulated with only an antioxidant (for protection during processing) and some pigment (usually carbon black) or other agent designed to screen out ultraviolet radiation in sunlight which, over long-term exposure, could be damaging to the natural-color polymer.

ASTM D 1248, the PE molding and extrusion materials specification, classifies these materials into three types depending on the density of the natural resin. Type I consists of lower-density materials which are relatively soft and flexible and have low heat resistance. Type II PEs are of medium density, slightly harder, more rigid, and more resistant to elevated temperatures; they also have better tensile strength. Type III materials show maximum hardness, rigidity, tensile strength, and resistance to the effects of increasing temperature. Pipe is made almost exclusively from Type II and Type III PEs. ASTM D 1248 also provides for grade designations to further classify PEs according to other physical characteristics. PE piping materials for pressure piping are classified by a designation system that combines the type and grade coding with that for the maximum HDS for water at 73.4° F (23° C). PEs used for pressure piping are listed in Table 6.

Outstanding toughness and relatively low flexural modulus, which permits coiling of smaller diameter pipe, are large factors in PE's prominence in gas distribution and water service piping. Other features, such as heat fusibility, good abrasion resistance, and availability in large diameters (up to 96 inches) account for the use of PE piping for chemical transfer lines, slurry transport, sewerage force mains, intake and outfall lines, and renewal (by insertion into the old pipe) of deteriorated sewers, gas, water, and other pipes.

Polybutylene (PB). Polybutylene is a unique polyolefin because its stiffness resembles that of low-density PE but its strength is higher than that of high-density PE. However, its most significant feature is its better retention of strength with increasing temperature. Its higher temperature limit is higher than that of any PE: nearly 200° F for pressure uses and somewhat higher for non-pressure applications.

PE piping materials are covered by ASTM D 2581. Pressure piping PBs are designated as PB 2110 (see Table 7), which indicates a maximum design stress of 1,000 psi for water at 73° F. At 180° F this design stress is 500 psi, the same value as for CPVC.

Major applications for PB piping take advantage of its improved temperature resistance. They include hot/cold piping and industrial uses such as hot/cold effluent lines. Because of its excellent abrasion resistance, PB is also used for slurry lines.

Acrylonitrile-Butadiene-Styrene (ABS). ABS comprises a family of materials that are formed from three different monomers (chemical building blocks): acrylonitrile, butadiene, and styrene. The properties of the components and the way in which they are combined can be varied to produce a wide variety of properties. Acrylonitrile contributes rigidity, strength, hardness, chemical resistance, and heat resistance; butadiene contributes toughness; and styrene contributes gloss, rigidity, and ease of processing.

ASTM D 1788 classifies ABS plastics into numbered cells that designate value ranges for each of three properties: impact strength (toughness), tensile stress at yield (strength), and deflection temperature under load. ABS pipe materials are categorized into Types and Grades in accordance with established minimum cell requirements for each Type and Grade. Like the other major thermoplastics, ABS materials for pressure pipe are designated by a coding that identifies both short-term properties and long-term strength. ABS pressure-pipe materials are listed in Table 7.

An advantageous combination of toughness with good strength and stiffness largely accounts for the most common uses of ABS pipe, i.e., for DWV applications as well as for sewers, well casings, and communications ducts.

A foam-core construction ABS pipe is commercially available. The wall of the product consists of thin inner and outer solid skins sandwiching a high-density foam. The primary benefit of this construction is improved ring and longitudinal (beam) stiffness in relation to the amount of material used. Applications of foam-core pipe are for non-pressure uses. A standard for a PVC pipe with a foam-core wall construction is under development at ASTM.

Polyacetal, also known as polyoxymethylene (POM), is a strong, hard, highly crystalline thermoplastic offering good rigidity, strength, and toughness, and relatively good temperature resistance. Because of these properties, POMs are increasingly being used to mold various hot/cold water plumbing components including valves, faucets, and compression fittings for use with PB and CPVC tubing.

Crosslinked PE. A new standard has recently been issued by ASTM which covers hot/cold water piping made from crosslinked PE (XPE). The crosslinking changes the PE from a thermoplastic to a thermoset and endows

TABLE 7

MAXIMUM RECOMMENDED HYDROSTATIC DESIGN STRESSES (RHDS) FOR THERMOPLASTIC PIPE MATERIALS FOR WATER AT 73° F

MATERIAL DESIGNATION[1]	MAXIMUM RHDS, IN PSI, FOR WATER AT 73° F[2]
PE 1404	400
PE 2305	500
PE 2306	630
PE 3036	630
PE 3406	630
PE 3408	800
XPE 330	630
PB 2110	1000
CPVC 4120	2000
PVC 1120	2000
PVC 1220	2000
PVC 2110	1000
PVC 2112	1250

[1] The first two digits code the material according to short-term properties. The last two digits code the maximum RHDS expressed in hundreds of pounds per square inch.

[2] Since thermoplastics, even though of the same material designation, may be affected differently by increasing temperature, RHDS for higher temperatures must be established for each specific commercial product.

the material with improved higher-temperature strength. Because they are crosslinked, these materials cannot be heat fused. XPE has not yet been commercially offered in the United States and it is not presently approved by any major plumbing code.

Styrene Rubber (SR). Styrene rubber compositions are combinations of polystyrene, in the greater part, with rubber. SR plastics are relatively strong and stiff. However, their impact strength is somewhat lower than other plastics, making SR more susceptible to damage by impact, particularly during cold weather.

SR plastics are used exclusively for non-pressure applications. Once relatively popular, they are now used little, having been largely displaced by the other materials.

Solvent Cement Materials. Solvent cements, which are often used when joining PVC, CPVC, and ABS piping, are compositions consisting essentially of a solvent, or combination of solvents, in which has been dissolved a quantity of the base plastic material sufficient to give the cement the body and consistency required for proper applications. Small amounts of inert fillers are sometimes also added to control these properties as well as shrinkage during drying. The principal solvents used include tetrahydrofuran (THF) for PVC and CPVC cements and methyl ethyl ketone (MEK) for ABS cements. To control rate of drying and other properties, PVC, CPVC, and ABS cements will sometimes include other solvents, most often cyclohexanone (CH) and dimethylformamide (DMF). As in the case of pipe, solvent cement compositions for use with potable water piping must be approved for this purpose by NSF or an equivalent authority.

FUTURE TRENDS

The generally successful use of plastics piping over the past 30 years has demonstrated that it is a cost-effective alternative for many water distribution and plumbing applications. As with any new material, some performance problems have occurred but in each case the underlying causes have been identified and appropriate correction measures taken. None of the noted problems suggests any inherent limitations by any of the plastics piping systems to providing reliable and long-term service for the intended applications. Enhancement in quality assurance requirements of current standards and better attention to certain installation practices have always been satisfactory resolutions to any noted performance inadequacies, except, of course, for cases of clear misapplication of the product.

Whenever surveys have been conducted comparing the performance of plastics to traditional piping materials, plastics have always shown up well. For example, a recent survey conducted by the American Gas Association indicates that during the year 1981 the reporting gas distribution companies have experienced leaks in plastic piping at a rate only 40 percent of that experienced for metallic piping, with no evidence that any significant problems are indicated with currently available materials.

A survey during 1981 by the American Water Works Association (AWWA) Standards Committee on Thermoplastic Pressure Pipe revealed no reported problems with PVC C 900 pipe in water distribution. In an AWWA survey during 1982 for polyolefin water service pipe, 80 percent of the respondents replied that their experience with these materials shows them to be as good as, and more often than not better than, conventional materials. An investigation of the other 20 percent by a private consultant disclosed that improper installation and a problem with a limited production run of one pipe product accounted for a higher incidence of problems. Both of these causes have been addressed by the addition of appropriate quality assurance requirements and broader adoption of good handling and installation practices.

From the first introduction of plastics piping, producers and users have been alert to identify and correct problems with plastics. This is evident by the intense activity in such standard writing organizations as ASTM, AWWA, API, and NSF in enhancing plastic piping product standards by adopting the lessons of technology and experience to better define the end product and its proper application. The result is the steadily improving performance reliability and durability of plastics piping.

The primary obstacle to increased utilization of plastics is not any inherent lack of capability but rather the exploitation of public and worker concerns over safety and health risks that are often associated with synthetic materials. The following allegations have been offered in support of restricting the acceptance of plastics piping: The possible leaching of toxic substances that could be present in plastic materials into drinking water; health risks to the worker and user created by the use of solvent cements to join plastics piping; health risks by the possible permeation through the pipe wall of toxic substances that might be present in the soil in contact with buried piping; fire and accompanying toxic gas hazards posed by the combustibility of plastics; and decreased labor utilization because of the greater ease of installing plastics. Obviously, any concern dealing with public and worker health and safety deserves to be duly considered and any necessary precautionary measures must be incorporated into product standardization and utilization. For plastics such scrutiny and action, which shall be elaborated by others in this workshop, is a matter of record since the first use of these materials for piping. For example, the NSF requirements date back to the late 1950s.

All the objective scrutiny that plastics piping has been receiving since that time points to the conclusion that these materials, when properly used, present no significant health and safety risks to the public and to the installer. Consequently, there is no apparent basis for speculating that the acceptance of plastics in general, or any material specifically, may be curtailed by water quality/material problems. Rather, future trends in market share shall be largely influenced by technical developments in materials and products which will affect their ease of application, performance, and ultimate best effectiveness. To this end there is considerable activity by a number of plastics piping interests.

There is also considerable activity, as evidenced by this workshop, in scrutinizing the effects of plastics and other materials on water quality. Such balanced scrutiny is appropriate and welcomed. In the case of plastics this might result in revision or additions to current material requirements which, if needed, can readily be included into an existing system, an opportunity that does not exist for the other piping materials.

IMPACT OF LEAD PIPING AND FITTINGS ON DRINKING WATER QUALITY

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HISTORICAL PERSPECTIVES

Lead pipe for conveying drinking water has been used for centuries (1). Among the known advantages of lead are its flexibility, durability, and long life. For these reasons, lead was used extensively in the United States beginning in the nineteenth century. Unfortunately, the hazards of using lead pipe, which were known at the time, did not deter many public water systems from using the material.

For example, in 1845 a report on water supplies for the city of Boston (2) concluded that:

> Considering the deadly nature of lead poison, and the fact that so many natural waters dissolve this metal, it is certainly [in] the cause of safety to avoid, as far as possible, the use of lead pipe for carrying water which is to be used for drinking. The best substitute is found in a pipe well coated with pure tin on the interior -- such pipes being quite safe and in every way preferred.

However, this warning was not heeded, and in 1899 Clark (3) reported that in addition to Boston, 70 other communities in Massachusetts reported the use of lead or lead-lined service pipes. Commenting at length on Clark's work, Forbes (4), in an address to the members of the New England Water Works Association in 1900, concluded that Clark's work showed:

> The many causes which make it possible for water to dissolve lead, and should teach us to look with extreme caution to the use of lead service pipes. It is also quite a serious matter, from a financial standpoint, to invest thousands of dollars in lead pipe, and then find that we have an element of serious danger in our midst which, sooner or later, must be remedied. The health of a community must first be considered; this goes without saying.

> Now, in light of so much conclusive evidence which is within our reach, what position should we take in this matter in constructing and maintaining a system of water works? Is it not wiser and better to eliminate all possible elements of danger from a thing so vital as the water which we must daily take into our bodies? We must bear this fact in mind; that ordinary citizens know little about these things, and trust to those who have charge of the water supplies to furnish them with a good and safe water and we should not be unmindful of the confidence placed in us.

Again the warning was not heeded. In a survey of water utilities in 1924, Donaldson (5) reported that 51 percent of the 539 cities surveyed across the country indicated they used lead or lead-lined services to some extent.

More recently, two nationwide surveys have demonstrated that lead is still a significant problem for some water supplies. In a study of 969 water supplies, McCabe et al. (6) concluded that 2 percent of the population served was receiving lead in excess of the mandatory limit of 0.05 milligram per liter (mg/1). Patterson (7), in a survey of 580 cities, found that 2.5 percent of the water samples exceeded 0.05 mg/1.

In a more recent survey (8) conducted by the U.S. EPA of 153 of the largest water systems in 41 states, 112 systems indicated they had used lead services during some period of time. However, at the time of this survey only the City of Chicago continues to install lead services, as mandated by their planning code. Lead goosenecks have also been widely used and 94 systems indicated their use in the past.

MONITORING FOR LEAD IN DRINKING WATER

Current EPA regulations (9) for monitoring trace metals in drinking water require that one sample per year be taken for lead at a consumer's tap. In the author's opinion, a single sample per year is inadequate to assess the concentrations of lead in drinking water from the corrosion of lead pipe. Among the variables that have to be considered in a sampling scheme to detect lead are contact time, water temperature, length of lead pipe, and water quality. In order to assess the variation in lead concentration in drinking water that had been standing for varying lengths of time in piping, it was considered necessary to collect three samples at each home. Samples were collected by the homeowners who followed the instructions in Table 1.

Samples were collected at the kitchen sink the first thing in the morning before any water was used in the home. Sample 1, the interior plumbing sample, was collected immediately upon opening the faucet. This represented water that had been standing overnight in the fixture and interior plumbing serving the faucet. Sample 2, the service line sample, was collected after the sample collector felt a temperature change in the

TABLE 1

SAMPLING INSTRUCTIONS

After 11:00 p.m., do not use the kitchen cold-water faucet until collecting the water samples the next morning. Using the following directions, in the morning, collect the water samples at the faucet before using any faucet or flushing any toilets in the house. Fill the provided containers to one inch below the top and put the caps on tightly.

Sample 1:	Open the cold water faucet, immediately fill bottle No. 1 and turn off the water. Recap this bottle.
Sample 2:	Turn the faucet on and place your hand under the running water, and immediately upon noticing that the water turns colder, fill bottle No. 2. Recap this bottle.
Sample 3:	Allow the water to run for three additional minutes and then fill bottle No. 3. Recap this bottle.

The man from the Environmental Protection Agency will stop at your house on the morning of ____________, to pick up the samples. if you do not expect to be home, please leave the samples outside the front door.

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water from warm to cold. Since water would be expected to warm slightly after standing in interior plumbing, this cold water would represent water that had been standing overnight just outside the foundation of the house in contact with the interior of the lead service line underground. Sample 3, the water main sample, was collected after the water was allowed to run for several minutes. This represented water that would have a minimum of contact time with the service line and interior plumbing.

The author feels that this method of sample collection is a realistic representation of the range of lead concentrations which the consumer is likely to find in the water he drinks. It is certainly conceivable that the first sample of water might be drawn directly by the homeowner in the morning and used to make juice or coffee, or drunk directly. The second sample, representing the usually colder water standing in the service line, could be drawn by a person trying to obtain the coldest water possible to drink. The third sample, taken after running the water, represents water that would be found more commonly during the day when water is used frequently for flushing toilets and cooking.

WATER QUALITY RESULTS

In order to assess the contribution to lead in drinking water from lead pipe, water samples were collected at consumers' taps supplied through a lead gooseneck or service line in Boston, Chatham, and New Bedford, Massachusetts, and Bennington, Vermont.

Although it is recognized there may be other contributors of lead, such as lead/tin solder, brass or galvanized pipe, or bronze fittings in the systems, all homes selected for sampling in Boston, New Bedford, and Bennington had lead service lines and those in Chatham had lead goosenecks, which are expected to be the major contributors of lead in these systems.

Table 2 lists raw water quality data for various parameters for each of these systems. It should be noted that all are very low in alkalinity, hardness, and pH, with lead concentrations in the sources of supply below the detection limit of 0.005 mg/l.

Table 3 shows the quality of water at consumers' taps after that water passed through the distribution system, the lead service line or gooseneck, and the internal plumbing. In each system, significant numbers of samples contained lead in excess of the Maximum Contaminant Level (MCL) of 0.05 mg/l. The lowest number of samples exceeding the standard occurred in Chatham, where there were lead goosenecks of approximately 2 feet in length. The other systems, where there were longer lead service lines running from the water main in the street to the house, had a greater proportion of samples in excess of the MCL.

In Bennington, where the water was extremely corrosive, 28 of the 30 samples exceeded the MCL. The percentage of samples containing lead

TABLE 2

RAW WATER QUALITY DATA*

	BOSTON	CHATHAM	NEW BEDFORD	BENNINGTON
pH	6.5	6.3	6.0	5.5
Hardness as $CaCO_3$	14	20	10	6
Alkalinity as $CaCO_3$	8	3	8	2
Sodium	5	11.9	6.5	1
Zinc	<0.02	<0.02	<0.02	<0.02
Copper	<0.02	<0.02	<0.02	<0.02
Lead	<0.005	<0.005	<0.005	<0.005

*All values except pH in mg/l

TABLE 3

DRINKING WATER QUALITY AT CONSUMERS' TAPS BEFORE CORROSION CONTROL*

	BOSTON	CHATHAM	NEW BEDFORD	BENNINGTON
No. Homes Sampled	10	14	10	10
No. Samples	42	30	30	30
No. Samples Pb >0.05	28	4	14	28
No. Samples Pb >0.005	42	20	26	30
Avg. Pb Concentration	0.128	0.017	0.06	0.158
Highest Lead Concentration	0.870	0.098	0.26	0.475
pH	6.5	6.3	7.3	5.5

*All values except pH in mg/l

greater than the detection limit ranged from 66 percent in Chatham to 100 percent in Boston and Bennington, indicating that all water reaching the tap was picking up some lead. The average lead concentration for all samples in Boston, New Bedford, and Bennington was above the MCL.

The foregoing illustrates the effect of the corrosive nature of low pH soft water on various lengths of lead pipe ranging from short, 2-foot lead goosenecks to service lines as long as 200 feet.

REMEDIAL ACTION

As a result of the identification of the problem of corrosion of lead pipe and the resulting high lead concentrations in drinking water, Boston, New Bedford, and Bennington instituted corrosion control in an attempt to reduce lead concentrations. Table 4 shows the results of corrosion control in each of these three systems.

In Boston (10), the pH was raised to 8.2 using sodium hydroxide, resulting in a significant decrease in average lead concentrations and in the number of samples exceeding the lead MCL. There are still a large number of samples exhibiting some pickup of lead. A similar situation occurred in New Bedford, where the pH and carbonate alkalinity were raised using sodium carbonate (soda ash). Again, significant reductions occurred in average lead concentrations and in the number of samples exceeding the MCL. In Bennington, corrosion control involved the addition of a combination of sodium hydroxide and sodium bicarbonate to raise both the pH and carbonate alkalinity. This appears to be the most effective treatment in that the average lead concentration was reduced to the lowest level and the number of samples with detectable levels was also the lowest. However, like Boston and New Bedford, there are still a small number of samples (three in each system) with lead greater than the MCL.

It would appear that the final solution to the problem involves both corrosion control and systematic replacement of existing lead services over time, giving priority to the worst-case situations, since corrosion control alone, while highly effective in reducing lead, does not completely eliminate the problem.

SUMMARY, CONCLUSION, AND RECOMMENDATIONS

1. Widespread use of lead service lines and goosenecks occurred in many water systems.

2. Many water systems have less than the optimum treatment for controlling lead corrosion.

3. High lead concentrations in all communities studied can be found if water samples are taken in a careful, systematic manner.

TABLE 4

DRINKING WATER QUALITY AT CONSUMERS' TAPS AFTER CORROSION CONTROL*

ITEM	BOSTON	NEW BEDFORD	BENNINGTON
No. Homes Sampled	13	8	10
No. Samples	39	24	30
No. Samples Pb >0.05	3	3	3
No. Samples Pb >0.005	29	21	11
Average Pb Concentration	0.020	0.026	0.014
Highest Lead Concentration	0.134	0.118	0.096
pH	8.2	8.5	8.1

*All values except pH in mg/l

4. The Interim Primary Drinking Water Regulations requiring only one sample per year are inadequate to identify the presence and amount of lead resulting from corrosion.

5. The solution to the problem of lead involves systematic removal of lead materials, and water treatment to reduce corrosion.

6. Although lead services are a major contributor of lead, other sources such as lead/tin solder must also be considered in any overall control strategy.

7. The author recommends the use of lead as an acceptable material for conveying drinking water be removed from plumbing codes.

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IMPACT OF COPPER, GALVANIZED PIPE, AND FITTINGS ON WATER QUALITY

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INTRODUCTION

The stated purpose of this seminar is to review drinking water problems associated with various plumbing materials. This presentation will explore the impact of galvanized steel and copper piping materials on water quality. This is a concern of environmental scientists who are evaluating the health hazard associated with the corrosion of these materials in a drinking water system.

For a corrosion engineer, the first instinct is to investigate the reverse issue; what effect does the water quality have upon copper or galvanized pipe? Although this is a subtle difference, both viewpoints have a common focal point. Each is concerned with the chemical or physical reaction of a metal with its environment, a sample definition of corrosion. Corrosion engineering is the application of science and art to prevent or minimize corrosion damage economically and safely. Therefore, the corrosion engineer will select the best available piping material that is compatible with the water quality, while considering other factors such as cost, safety, and regulations. This includes the National Drinking Water Regulations, which establish Maximum Contaminant Levels (MCLs) for several metals found in copper or galvanized steel systems.

Copper and galvanized steel have found widespread use in potable water systems for many years. Experience has shown that both materials have good corrosion resistance to drinking water when properly selected and properly installed. Either can be subject to corrosion failures or contribute to the health hazards problem when abuses occur in designing the system or by installation procedures. The National Association of Corrosion Engineers (NACE) has published guidelines (4) for architects, design engineers, and plumbing contractors to call attention to the corrosion problems in these systems which they should be aware of.

Table 1 presents some of the constituents found in drinking water that define water quality. Many investigators have reported on the impact of the various constituents on the corrosion of copper piping materials (5-11), galvanized steel (12-21), and copper alloys (22-25). With the exception of lead, only in recent years has the impact of piping materials upon water quality been investigated to any extent. This presentation will review recent literature and report recent findings of the author and coworkers on the subject.

CORROSIVE QUALITIES OF DRINKING WATER

Some investigators have attempted to classify drinking waters according to their potential to be corrosive to piping materials. Campbell (5) classified waters by the water source and treatment rather than by chemical analyses. Types of water recognized by Campbell were: deep well waters, which are not usually corrosive to galvanized steel but may produce pitting in copper; upland surface waters, which are soft, have a low pH, and contain organic matter, and which are aggressive to galvanized steel and nonaggressive to copper; slow sand filtered surface waters, which contain a natural organic corrosion inhibitor for copper and are not corrosive to galvanized steel; and lime-softened waters with a high pH, which are nonaggressive to copper, but can be aggressive to galvanized steel in the absence of carbonate hardness. In similar matter, Obrecht and Myers (17) outlined fifteen categories for potable water, based on the corrosiveness and the scaling potential of the water supply. Calcium, silica, sulfate, dissolved oxygen concentrations, and temperature were employed to categorize the water. Lane and Neff (18) classified Midwest water supplies into five types, based on hardness, chloride and sulfate; pH; and alkalinity in a similar manner as Campbell.

Other investigators have attempted to employ predictive corrosion indices to identify waters that are aggressive. The Langelier Index (26) is the U.S. Environmental Protection Agency (EPA) recommended parameter for estimating corrosivity of public water supplies, although many corrosion engineers also employ the indices developed by Ryznar (27), Larson and Skold (28), Dye (29), McCauley and Abdullah (30), and others. These indices have been reviewed by Rossum and Merrill (31) and Singley (32).

The chemical constituents that are commonly cited by investigators as influencing the corrosivity of a water supply are calcium, alkalinity, pH, carbon dioxide, sulfate, oxygen, silica, and temperature. The unknown influences (organics, polyphosphates) and the interaction of all the constituents are not understood. None of the previously referenced papers provide information on the solubilization of metals from galvanized steel and copper pipe or their impact on water quality.

Lead concentrations exceeding the MCL value were reported in the Boston, Massachusetts, water supply by Karalekas et al. (33) and in Worcester, Massachusetts, by O'Brien (34) in the 1970s. Those studies,

Table 1. Common Constituents Found in Drinking Water

	Dissolved minerals	
Calcium	Hypochlorite	Bicarbonate
Magnesium	Fluoride	Carbonate
Sodium	Phosphate	Sulfate
Potassium	Borate	Chloride
Barium	Hydroxide	Nitrate
Strontium	Iron	Silica
Trace Metals	Manganese	
	Dissolved gases	
Oxygen	Hydrogen Sulfide	Methane
Carbon Dioxide	Nitrogen	Ammonia
	Suspended Matter	
Corrosion Products	Mineral Deposits	Microbial Organisms
	Miscellaneous	
Unidentified Organics	Trihalomethanes	

along with the development of analytical procedures capable of detecting trace metal concentrations (e.g., atomic absorption) and the passage of the National Safe Drinking Water Act, prompted several researchers to study the impact of plumbing materials on water quality.

METAL CONCENTRATIONS FOUND IN SAMPLES FROM HOUSEHOLD PLUMBING

The metals associated with copper or galvanized steel piping materials and fittings are zinc, copper, lead, tin, cadmium, and iron. Copper, zinc, and lead concentrations found in samples taken from household taps are presented in Table 2. All of the studies (33-39) referenced employed procedures for determining running and standing sample metal concentrations. Some of the studies were primarily concerned with lead concentrations contributed by lead service lines, although the samples were also exposed to the building plumbing materials.

Lead, copper, and zinc were found in concentrations that exceeded the MCL value. As anticipated, this occurred most frequently in the standing samples. Cadmium was not found in significant enough concentrations in household plumbing to be considered a potential health problem. Tin concentrations were not commonly reported and are not likely to be a potential problem in drinking water. Iron concentrations frequently exceed the MCL value in many water supplies as a natural occurring mineral and are a factor in corroding galvanized steel plumbing.

Newly installed plumbing materials that have not formed protective oxide films or mineral deposits are found to have very high zinc, copper, and lead concentrations when in contact with water for long periods of time. An example of this phenomenon occurred very inconveniently during a cooperative corrosion study the Illinois State Water Survey (ISWS) is conducting with EPA assistance. A corrosion test loop (Figure 1) was installed with new copper and galvanized steel piping in a public water supply to simulate normal household water usage. Approximately 40 feet of galvanized steel pipe was installed by licensed plumbers ahead of approximately 40 feet of copper tube employing 50 Sn:50 Pb solder fittings. Chrome-plated brass sample valves, brass shut-off valves, corrosion specimens, bronze water meter, and a PVC pipe nipple (to separate materials) were also employed in the test loop. Water flow was controlled by an electrically operated solenoid valve activated by a timer. The timer was programmed to allow water to flow 5 to 10 minutes every hour for 16 hours and then to shut down the system for 8 hours. Standing and running samples were taken after 7 to 8 hours of contact with the plumbing materials. When this test loop was first placed in operation, the timer failed and did not operate during the first 6 weeks. Two sets of samples were collected during the 34-day period in which the test loop was flushed one time after 15 days to collect running samples. Extremely high iron, zinc, copper, and lead concentrations were found in both copper and galvanized steel piping (Tables 3 and 4). Even after 5 minutes of flushing, the running samples continued to have a high zinc concentration.

Table 2. Metal Concentrations Found in Samples from Household Taps

			Concentration (µg/L)			
			Standing		Running	
Location	No. of sites	Metal	Mean	Max.	Mean	Max.
Worcester, MA	9	Pb	270	1900	0	0
Bridgeport, CT	10	Pb	10	40	<5	--
Marborough, MA	9	Pb	14	250	10	--
Chatham, MA	10	Pb	17	98	15	--
New Bedford, MA	10	Pb	76	260	13	--
Seattle, WA	34	Cu	450	2050	120	1670
		Zn	1740	5460	150	1730
		Pb	39	170	5	22
		Fe	1400	5400	280	1200
Trondheim, Norway	18 cities	Zn	348	2125	126	--
		Cd	--	8.6	--	--
		Cu	164	1100	52	--
		Pb	9.7	110	2.7	--
Netherlands	10 cities	Zn	344	650	--	--
		Cd	<0.5	0.5	--	--
		Cu	647	1870	--	--
		Pb	81	180	--	--

SIMULATED CORROSION TEST LOOP

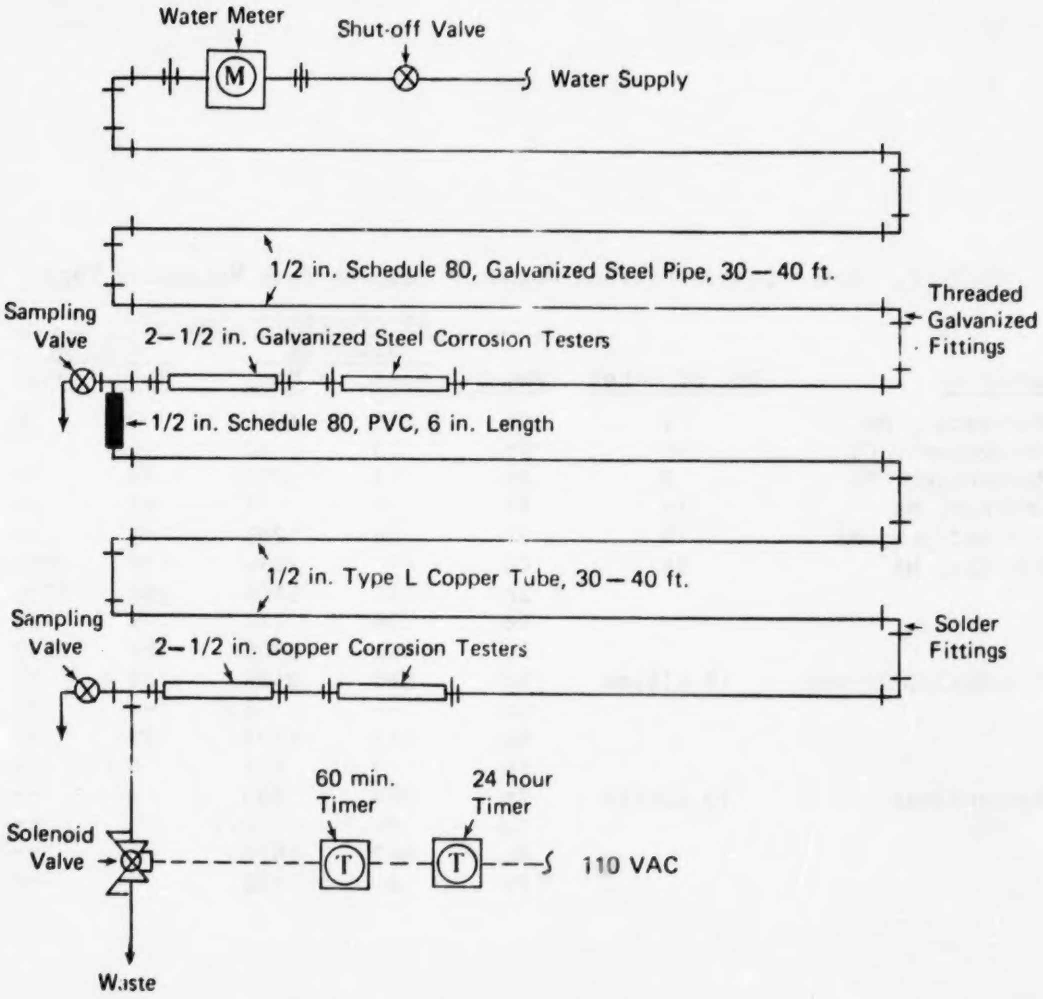
Water Meter
M
Shut-off Valve
Water Supply
1/2 in. Schedule 80, Galvanized Steel Pipe, 30 — 40 ft.
Threaded Galvanized Fittings
Sampling Valve
2—1/2 in. Galvanized Steel Corrosion Testers
1/2 in. Schedule 80, PVC, 6 in. Length
1/2 in. Type L Copper Tube, 30 — 40 ft.
Sampling Valve
2—1/2 in. Copper Corrosion Testers
Solder Fittings
60 min. Timer
24 hour Timer
T
T
Solenoid Valve
110 VAC
Waste

Figure 1

Table 3. Total Metal Concentrations (mg/L) of Samples from New Copper Plumbing*

Parameter		15 days, no flow	19 days, no flow	Normal operation
Standing	Pb	11.0	2.24	0.010
	Cu	1.687	0.343	0.005
	Zn	70.2	78.0	0.175
	Fe	14.3	7.43	0.13
	Cd	0.006	--	--
Flowing	Pb	1.89	0.330	0.004
	Cu	0.490	0.018	0.004
	Zn	17.4	31.0	0.090
	Fe	1.44	7.94	0.13
	Cd	0.001	--	--

* Note: Galvanized Plumbing Precedes Copper Plumbing

Table 4. Total Metal Concentrations (mg/L) of Samples from New Galvanized Plumbing

Parameter		15 days, no flow	19 days, no flow	Normal operation
Standing	Pb	0.770	0.710	0.001
	Cu	0.880	2.324	0.003
	Zn	67.60	11.2	0.150
	Fe	18.30	41.30	0.14
	Cd	0.009	--	--
Flowing	Pb	0.440	0.007	0.001
	Cu	0.013	0.005	0.003
	Zn	63.2	0.15	0.09
	Fe	2.66	0.11	0.12
	Cd	0.001	--	--

The metal concentrations increased again during the next 19 days of exposure to the stagnant water in the loop. Normal operation (Tables 3 and 4) refers to the metal concentrations found in samples from the test loops after the timer was replaced and programmed water flow was established.

This example dramatically indicates that extremely high lead, copper, zinc, and iron concentrations can occur within newly installed household plumbing. Such systems may require long flushing periods to reduce metal concentrations below MCL values. Stagnant water in household plumbing will frequently develop a bitter taste or turbidity due to the metal concentrations. A consumer would probably flush such a system until the water was palatable; however, the author is familiar with some galvanized steel systems in which taste problems and high zinc concentrations persisted for over a year after installation.

Plumbing materials do affect water quality. That impact is influenced not only by the plumbing materials but by water quality, velocity, temperature, exposed surface area, and system design. Most homes and buildings are unique when these influences are considered, and the wide variation of metal concentrations reported in the literature for drinking water is not surprising.

IMPACT OF BRASS MATERIALS ON WATER QUALITY

The metal concentrations reporeted in Tables 3 and 4 exceed their predicted solubility, which indicates suspended corrosion products were the major component responsible for exceeding MCL values. Lead concentrations were also seen as an indication that lead-tin solder was affecting water quality. The chrome-plated brass sampling valves were also suspected as a source of zinc, lead, and copper.

To determine the effect the brass sampling valves were having on standing metal concentrations, a series of samples were taken from the brass valve, which was then replaced with a high-density polyethylene valve. Another series of standing samples were collected until the corrosion test loop was permanently shut down. Table 5 shows the sudden decrease in zinc, copper, and lead concentrations that occurred immediately with the sampling valve change. Copper and lead concentrations were reduced to near analytical detection limits. Zinc concentration decreased to the background level contributed by the galvanized steel piping. The chrome-plated brass sampling valve was determined by these tests to be a major source of zinc, copper, and lead, even in the nonaggressive water employed at this site. The sequential collection of 125- milliliter samples also indicated that the brass sampling valve was influencing the standing metal concentrations for more than 20 valve volumes of water.

The chrome-plated brass valves were employed in the ISWS-EPA corrosion study to simulate the household sampling methods employed by the studies in Table 2. Other brass valves with copper tubing and solder connections and

Table 5. Influence of Valve Material on Total Metal Concentrations of Standing Samples

Date	Valve material	Zn (mg/L)			Cu (mg/L)			Pb (µg/L)		
		(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)
3/8	Chrome-plated brass	1.30	ND	ND	0.73	ND	ND	99	ND	ND
4/6	"	1.00	ND	ND	0.31	ND	ND	56	ND	ND
4/14	"	2.09	ND	ND	0.18	ND	ND	59	ND	ND
4/21	"	2.66	ND	ND	0.77	ND	ND	60	ND	ND
5/3	"	2.09	ND	ND	0.06	ND	ND	31	ND	ND
5/14	"	1.98	ND	ND	0.07	ND	ND	75	ND	ND
5/24	"	0.65	ND	ND	0.29	ND	ND	21	ND	ND
6/13	"	1.10	0.41	0.48	0.04	0.03	0.04	30	11	8
6/22	"	1.01	0.42	0.30	0.06	0.03	0.04	19	18	5
6/27	"	0.75	0.28	0.26	0.08	0.02	0.04	15	5	4
7/12	"	0.68	0.69	0.25	0.03	0.04	0.04	13	23	4
7/16	Polyethylene	0.30	0.20	0.24	<.01	<.01	<.01	1	1	1
7/21	"	0.22	0.16	0.14	<.01	<.01	<.01	1	1	1
8/5	"	0.35	0.26	0.22	<.01	<.01	<.01	2	1	2
8/15	"	0.55	0.22	0.01	<.01	<.01	<.01	1	1	1
8/22	"	0.46	0.21	0.17	<.01	<.01	<.01	1	1	1

a -- first 125 mL of water drawn from valve
b -- second 125 mL of water drawn from valve
c -- third 125 mL of water drawn from valve
ND -- not determined

more surface area may influence metal concentrations to a greater extent. Samuels and Meranger (40) recently reported on metal concentrations leached from eight types of new chrome-plated brass kitchen faucets by water of varying quality. Data for three faucets are shown in Table 6. The authors concluded that copper, zinc, chromium, cadmium, and lead were leached from the faucets in varying amounts, depending on the type of faucet and the water quality. Chromium and cadmium in the leachate were not considered significant when compared to the MCLs for these metals. Werner (16) observed that considerable quantities of copper and zinc were being contributed by brass fittings and may be a significant factor in the corrosion behavior of galvanized steel. These studies confirms ISWS observations. Any attempt to correlate standing metal concentrations to the corrosion of galvanized steel pipe, copper tube, lead service lines, and solder should be preceded by isolating the system with plastic sampling valves.

Brass or bronze water meters are also suspected to have similar metal dissolution patterns as brass valves. Water meters are usually installed in service line or piping near the entrace of the water into the household. Standing or running metal concentrations may be influenced by water meters for several system volume changes. The ISWS-EPA study will attempt to determine if water meters are, in fact, contributing to the metal concentrations of drinking water.

IMPACT OF MATERIALS VS. AGE OF SYSTEM

Metal concentrations found in samples exposed to stagnant water have been discussed. This condition occurs only when homes are first built, during vacation periods, etc. During normal period of water usage, metal concentrations in samples are found to be much lower. Figure 2 illustrates the change in zinc concentration with time of exposure. It also demonstrates the difference in zinc concentration of established galvanized steel plumbing (site 313) and new galvanized steel plumbing (site 315). Zinc concentrations exceeded the MCL value for the first 9 months for the new plumbing and required the entire 24 months of the study to attain equivalent zinc concentrations found in the established system. In the older system, zinc concentrations did not exceed the MCL for any sample during the 24-month study and remained relatively constant for the entire period. The decrease in metal concentration with time was also observed for copper, lead, and zinc concentrations at other sites where new plumbing materials were employed. The standing and running copper concentrations at site 314, a copper test loop, are illustrated in Figure 3 showing the same decline in copper concentration as seen for galvanized steel in this particular water supply. The "spikes" or wide fluctuation in metal concentrations was observed for all newly installed piping systems.

With the increased contact time of piping materials with water, corrosion films may become more adherent and cover more surface area to reduce metal concentrations found in samples. The "spikes" in

Table 6. Total Metal Concentration Leached from Kitchen Faucets

Sample description			Faucet No. 1			Faucet No. 5			Faucet No. 6		
			Cu	Zn	Pb	Cu	Zn	Pb	Cu	Zn	Pb
Source	Leaching	pH	mg/L	mg/L	µg/L	mg/L	mg/L	µg/L	mg/L	mg/L	µg/L
Raw Water	1st	7.4	0.69	0.59	4.3	1.68	0.51	31.0	0.65	2.80	26.0
	2nd	7.4	0.83	0.40	3.4	0.43	0.65	20.0	0.41	1.70	24.0
Filtered Water	1st	6.3	1.82	2.75	1.4	0.78	1.15	55.0	2.47	2.55	26.0
	2nd	6.3	1.40	2.25	1.5	0.41	0.55	26.0	0.74	1.10	15.0
Treated Water	1st	8.4-8.6	1.03	0.40	0.7	0.37	0.39	49.0	3.33	4.70	45.0
	2nd	8.4-8.6	0.61	0.18	0.7	0.16	0.10	15.0	1.32	2.85	24.0
Well Water	1st	8.1	0.85	0.57	0.8	0.43	0.85	4.1	9.65	4.85	58.0
	2nd	8.1	0.28	0.46	0.4	0.30	0.51	1.8	3.54	2.00	45.0
Fulvic Acid (2 mg/L)	1st	6.2	0.19	0.55	4.3	0.65	0.37	110.0	1.76	1.32	18.0
	2nd	6.2	0.35	0.29	7.4	0.26	0.25	82.0	1.01	0.74	20.0

Re: Samuels and Meranger

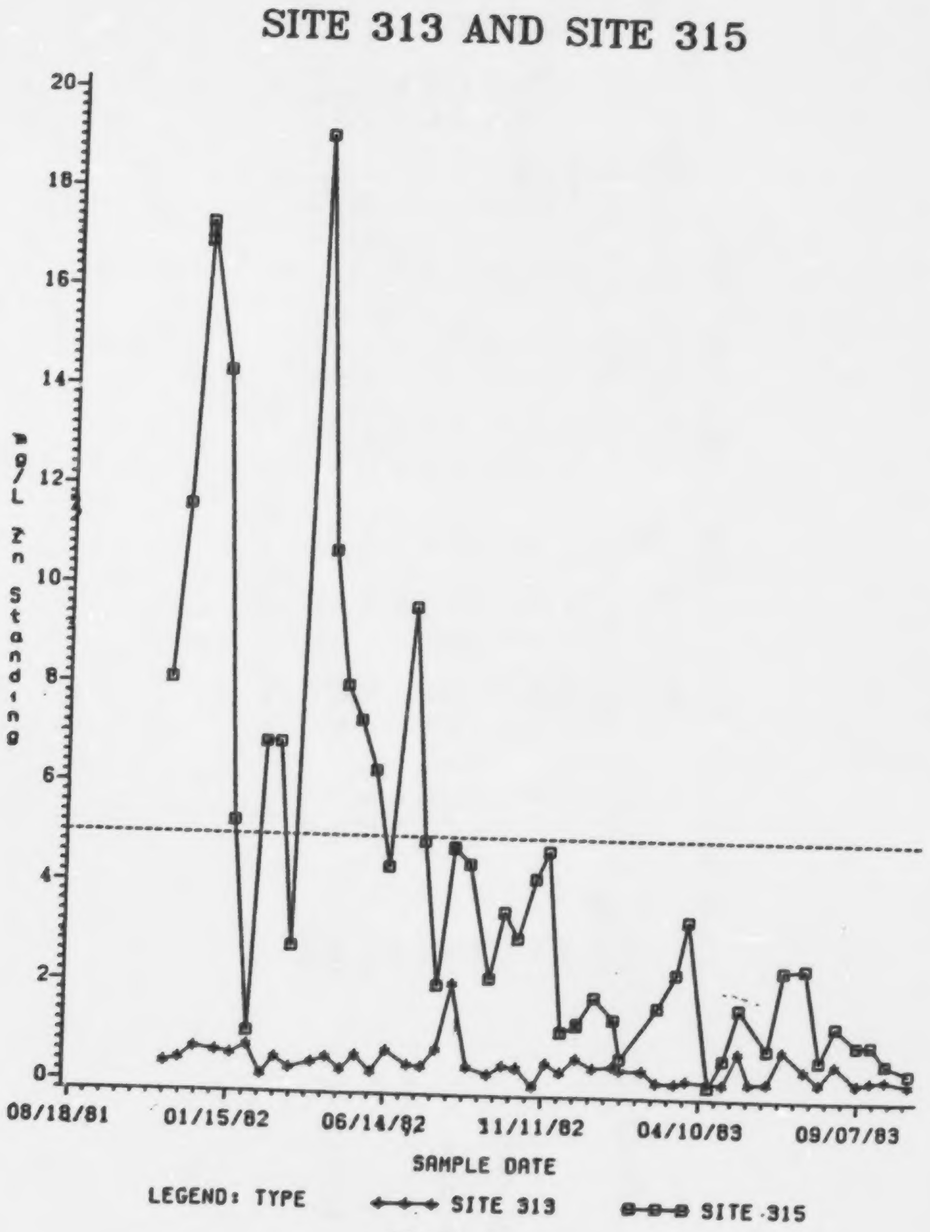
SITE 313 AND SITE 315
ug/L Zn Standing
20
18
16
14
12
10
8
6
4
2
0
08/18/81
01/15/82
06/14/82
11/11/82
04/10/83
09/07/83
SAMPLE DATE
LEGEND: TYPE
SITE 313
SITE 315

Figure 2

SITE 314

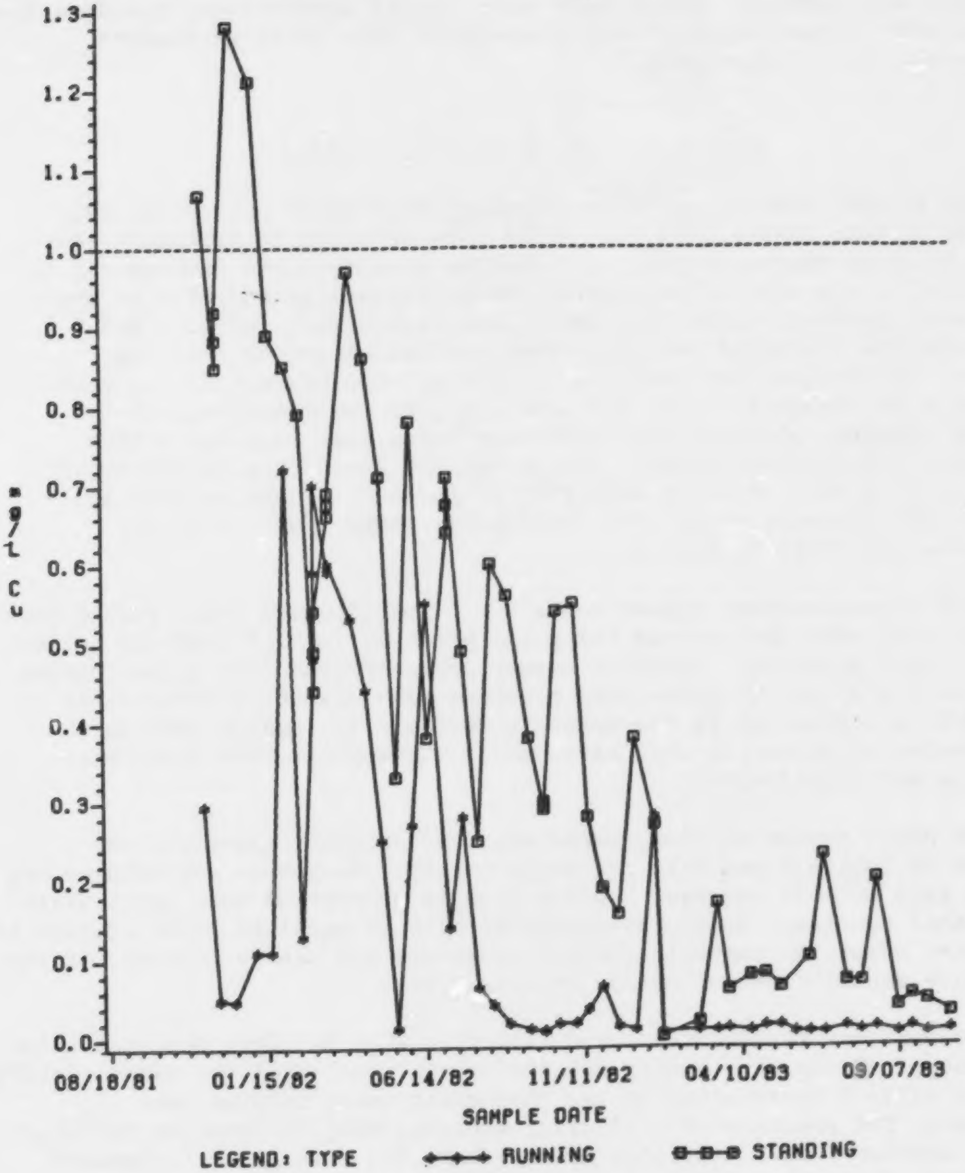

Figure 3

concentration values were assumed to be due to loose corrosion products being transported through the plumbing. Contamination of drinking water by zinc corrosion products in West Germany and referred to as "Zinkgeriesel" has been reported by Werner (16). Serious corrosion damage of galvanized steel has occurred in new buildings in which the corrosion products were observed. Older buildings did not experience this type of damage. Irregular zinc coating, faulty weld seam, faulty connections, residues from construction, brass fittings, and temperature were noted as factors responsible for "Zinkgeriesel."

NATURE AND SOURCE OF METAL CONTENT

Due to the "spikes" and some extremely high metal concentrations observed at some test sites, four sites were selected to determine the nature of metal contamination. A filtering procedure was implemented to periodically determine soluble metal concentrations in addition to the total metal concentrations of samples from each site. Tables 7 and 8 illustrate how the metal concentrations are influenced by sampling sequence, filtration, and plumbing materials. The brass sampling valve appears to be responsible for the zinc and lead concentrations in the standing samples, although the galvanized steel test loop has a high background zinc concentration. The galvanized steel pipe is the major contributor of zinc which is more than 85 percent soluble at site 315. Soluble zinc concentrations were observed to range from 1.0 to 2.6 milligrams per liter (mg/l) Zn.

Lead concentrations appear to be due to particulate lead, rather than soluble lead, with the sources being the brass valves and lead-tin solder of the copper plumbing. Standing copper concentrations are 17 micrograms per liter (g/l) in the galvanized plumbing with higher concentrations of 57 to 370 g/l observed in the copper plumbing. The copper tube is the major source of copper at this site, while the contribution from brass valves is not significant.

The major source of iron, manganese, and calcium concentrations observed in Tables 7 and 8 is the water supply. Manganese and calcium are present as a soluble species, whereas iron is present as both particulate and soluble species. Sodium hexametaphosphate (5 mg/l) is being applied to this water supply to control iron and manganese and may be influencing the solubility equilibriums of metals at this site.

Another observation from these tables is that calcium, manganese, and iron concentrations of standing samples are indicative of the water quality at these sites 8 hours prior to the time the running samples were collected. The practice of collecting standing samples prior to collecting running samples infers that both samples have the same general chemical characteristics, other than metal concentrations, which is often untrue.

Table 7. Metal Concentrations from Copper Plumbing (Site 314)*

	Sampling Procedure		Total metal concentrations (µg/L)					
Date	Flow condition	Filtered (0.4 µM)	Zn	Fe	Cu	Pb	Mn	Ca
2/24	Standing, 1st 125 mL	No	217	72	254	277	85	73
	2nd 125 mL	No	102	36	97	37	82	72
	3rd 125 mL	Yes	74	16	70	5	80	72
	Flowing, 10 min.	No	50	1480	13	1	224	118
	10 min.	Yes	50	830	12	1	211	118
4/28	Standing, 1st 125 mL	No	180	430	280	86	85	74
	2nd 125 mL	No	160	210	92	35	84	74
	3rd 125 mL	Yes	80	170	63	15	81	73
	Flowing, 10 min.	No	30	560	3	2	65	47
	10 min.	Yes	60	390	4	1	80	58
6/28	Standing, 1st 125 mL	No	280	2000	370	85	220	106
	2nd 125 mL	No	230	1680	150	15	230	107
	3rd 125 mL	Yes	150	380	57	7	180	106
	Flowing, 10 min.	No	60	890	7	32	30	35
	10 min.	Yes	30	270	5	7	40	34

* Note: Galvanized Plumbing Precedes Copper Plumbing

Table 8. Metal Concentrations for Site 315 (Galvanized Steel)

	Sampling Procedure		Total Metal Concentrations (μg/L)					
Date	Flow Conditions	Filtered (0.4 μM)	Zn	Fe	Cu	Pb	Mn	Ca
2/24	standing, 1st 125 mL	no	1220	1360	11	90	99	73
	standing, 2nd 125 mL	no	1210	1060	17	61	100	72
	standing, 3rd 125 mL	yes	1040	240	5	7	93	71
	flowing, >10 min	no	60	1470	4	4	229	116
	flowing, >10 min	yes	60	590	4	2	203	115
4/28	standing, 1st 125 mL	no	1350	2010	7	194	98	76
	standing, 2nd 125 mL	no	1230	380	8	19	84	74
	standing, 3rd 125 mL	yes	1170	230	3	8	80	76
	flowing, >10 min	no	50	540	3	2	70	58
	flowing, >10 min	yes	30	370	2	2	80	63
6/28	standing, 1st 125 mL	no	2960	2250	8	18	240	107
	standing, 2nd 125 mL	no	2880	1480	8	8	240	106
	standing, 3rd 125 mL	yes	2640	180	6	2	210	107
	flowing, >10 min	no	90	1440	7	3	60	38
	flowing, >10 min	yes	50	540	6	2	80	45

IMPACT OF DESIGN AND INSTALLATION PROCEDURES ON WATER QUALITY

The selection of the proper piping materials is the most important single factor in designing a potable water system. The experiences of Campbell (6), Obrecht and Myers (17), Cohen (10), Lane and Neff (18), and others provides some guidelines for this selection; however, local experience should weigh heavily on the selection process. Although the proper material may be selected, poor pipe quality can be responsible for rapid failure. Galvanized steel pipe in recent years has had frequent occurrences of defective or inadequate zinc coatings. The quality of copper tube has been consistent, although carbon films formed in the manufacturing process have been reported to cause pitting. Piping should be inspected prior to installation. Perhaps tighter piping specifications and quality control procedures are required for materials exposed to drinking water.

Poor plumbing practices or "shoddy" workmanship can also result in corrosion of plumbing materials. It is not uncommon to observe dissimilar metals joined together, excessive threading of pipe ends, excessive use of flux and solder, inadequate reaming of pipe ends, or other manifestations of poor plumbing practice. Each of these factors can contribute to copper, zinc, or lead content of potable water, although the quantities contributed are not known.

A contributing factor to the corrosion of materials is velocity, which can be controlled by design. Copper tube is more susceptible to the erosion-corrosion attack by water than is galvanized steel. This type of corrosion is seen more often in recirculating water systems which have oversized pumps but has occurred in undersized copper tube in potable water systems. Unreamed tube ends may also cause flow disturbances that erode otherwise protective films in the vicinity of the fittings. It is not clear whether less adherent corrosion products or soluble copper is being generated by this corrosion process. Water velocity can influence corrosion rates and increase the transport of zinc corrosion products in galvanized steel plumbing.

Grounding of electrical circuits to water pipes in houses has been reported (41) to cause copper corrosion with resulting blue-water and copper concentrations of 6.5 mg/l. Corrosion by stray DC currents is well documented; however, stray AC current corrosion has rarely been documented. AC current corrosion has been reported (42) to increase with decreasing frequency; and at 5-Hz AC currents, corrosion is 1 percent of the equivalent DC current. Reliable information on the subject is not available; further investigation is warranted.

IMPACT OF WATER TREATMENT PRACTICES

A brief discussion is warranted on the water supply operations and maintenance program that can increase the corrosivity of the water toward copper or galvanized steel. Chemical treatment programs for the purpose of corrosion control, we will assume, are reducing the corrosion.

CONTROL OF WATER SUPPLY QUALITY

The water quality of public water supplies has been found to vary drastically over short time spans during the ISWS-EPA corrosion study. These fluctuations in water chemistry have been due to equipment failures, operation procedures, disinfection procedures, treatment change, and seasonal variations. Public water supplies are dynamic systems where chemical equilibriums control the solubility of metals and corrosion mechanisms. Any change in temperature, pressure, or ionic concentration, in an otherwise stable system, will influence corrosion. One example is a small community in Central Illinois which employs five wells for a source of water. Well operation follows a schedule which pumps one well for one day, another well the next day, and three wells the following day. The quality of the water from these wells is significantly different, as noted by sulfate, chloride, and hardness concentration ranges of 77 to 590 mg/l, 51 to 404 mg/l, and 265 to 364 mg/l, respectively. Without elaborating further, water plant operators in small communities need information and assistance to improve their awareness of operating practices which may upset a stable system (if one exists).

CHLORINATION IMPACT

Another significant change observed for water supplies in Illinois during the last 10 years has been a decision by many water suppliers to abandon lime-softening and by other water suppliers to change to free residual chlorine disinfection methods. Economic reasons have probably been responsible for the change from lime-softening to clarification-only treatment, while the Illinois EPA has encouraged free residual chlorination methods. We have observed 2 to 4 mg/l free residual chlorine in some supplies in order to maintain minimum residuals in the extremities of the system. Application of sodium silicate and increased pH reduced the corrosion that had been caused by high, free chlorine residuals in a copper system of a state mental health facility. At another facility, pitting failures of copper heat exchangers were reduced by lowering free chlorine residuals from 2 mg/l to 1 mg/l. Increased solubilization of copper by chlorine, which is pH dependent, has been cited in the literature (43).

POLYPHOSPHATE TREATMENT

The usage of polyphosphates to sequester iron has found widespread acceptance among small water suppliers, since this alternative is more economical than other iron removal processes and has the added benefit of removing tuberculation from cast iron piping. It is this latter ability to solubilize corrosion products which concerns the author.

Early reports (44,45) on the effect of polyphosphates on lead pipe concluded that polyphosphates inhibited lead solubility below pH = 7.0 but slightly increased lead solubility above pH = 8.8. One author (45) concluded: "Since the amount of lead taken up by waters of high pH value is relatively small, the increase due to the addition of metaphosphate does not seem to indicate any serious danger to public health, except possibly in softened waters which employ metaphosphate for recarbonation."

In this paper, the reported standing lead concentrations from lead pipe exposed at pH = 8.8 increased from 0.33 mg/l to 0.79 mg/l Pb as the metaphosphate dosage was increased from 0 mg/l to 10 mg/l. To this author, those lead concentrations appear significant, as are some lead values observed in the ISWS-EPA study.

Preliminary mean metal concentrations are reported in Table 9 (copper systems) and Table 10 (galvanized steel systems). Water supplies D and E contained 1.0 and 4.0 mg/l polyphosphate (as PO_4), while water supply A temporarily contained 0.5 mg/l polyphosphate. These three water supplies have been exceeding the lead MCL value seriously at site 314, causing concern that the polyphosphate may be increasing the solubility of lead from lead-tin solder or brass fittings. Continued research on the effects of polyphosphates on plumbing materials is required due to the potential health hazard of these effects.

SUMMARY

Many studies have shown that copper tubing, galvanized steel pipe, and brass fittings have increased the lead, zinc, iron, and copper concentrations in drinking water. Water quality and water treatment will influence the degree of impact these plumbing materials will have. The MCLs for these metals have been exceeded most often in standing samples from household taps. Brass sampling valves may have made a significant contribution to the metal concentraions reported in many studies. Newly installed copper or galvanized steel plumbing may require several months to attain stable, minimum metal values in the drinking water. Stability may never be achieved in some water supplies due to fluctuating water chemistry. Disinfection methods and polyphosphate usage may also increase the solubility of metals from copper or galvanized plumbing.

Continued research is required to identify the sources of these metals and to control their solubility in drinking water. Basic information is needed on the nature of protective corrosion films, the influence of complexing agents on the film, and the water chemistry necessary to form the films.

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Table 9. Mean Metal Concentrations (μg/L) Observed in Copper Plumbing (approx. 45 samples per site)

Site	Water Supply	Plumbing Age	CuR	CuS	FeR	FeS	PbR	PbS	ZnR	ZnS
301	A	new	37	267	89	215	14	106	166	403
303	A	old	7	25	53	57	1	3	26	85
305	B	new	25	188	60	142	1	17	24	84
307	B	old	8	37	50	53	1	2	20	22
308	C	new	489	1327	144	287	4	42	1116	2358
310	C	new	555	1277	164	134	5	10	1678	4331
312	D	new	258	675	177	759	30	170	24	202
314	E	new	125	419	1107	1408	455	2125	207	348
316	F	new	15	287	51	93	14	183	25	379
318	F	new	10	95	56	58	4	70	66	597

R -- running samples S -- standing samples

Table 10. Mean Metal Concentration (µg/L)
Observed Galvanized Steel Plumbing
(approx. 45 samples per site)

Site	Water Supply	Plumbing Age	CuR	CuS	FeR	FeS	PbR	PbS	ZnR	ZnS
302	A	old	8	11	67	109	1	6	75	134
304	A	old	3	38	54	100	1	3	57	122
306	B	new	9	89	78	145	1	12	90	411
309	C	new	538	766	701	882	13	17	2214	5918
311	C	new	737	1411	244	677	6	15	3341	9845
313	D	old	27	79	150	150	4	8	156	418
315	E	new	10	39	1025	3009	5	213	365	4359
317	F	new	4	51	135	150	3	16	251	4376
319	F	new	5	16	70	320	3	80	286	6685

R -- running samples   S -- standing samples

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SUMMARY OF IMPACT OF METALLIC SOLDERS ON WATER QUALITY

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BACKGROUND

An incident of lead poisoning of a dentist's son in Smithtown, New York, prompted the consumer's request for testing of his home water supply. Water as a source of lead was discounted at first because the Water District had a 15-year record of lead-free distribution samples. Nevertheless, first-draw (zero to one minute) sampling showed lead in excess of the Drinking Water Standard of 50 micrograms per liter (μg/1). After three minutes of flow, sampling showed water well under the standard limit.

Lead solder was suspected as the source of the lead. Every home in the 8-year-old subdivision was tested. The two occupied homes with high first-draw lead levels both had recent plumbing additions using lead solder. A new home under construction had an even higher first-draw lead value of 7,100 μg/1.

Consulting engineers H2M/Holzmacher, McLendon & Murrell, P.C., conducted this testing and, at the same time, initiated an American Water Works Association (AWWA) literature search for studies of lead solder. Prior studies in the United States, Canada, and Europe showed high lead values in first-draw water after periods of non-use. The lead values were higher in water systems with low pH and soft water. Further studies were then conducted by H2M in Nassau and Suffolk counties, New York, to investigate the occurrence of lead leaching from new and old lead solder joints.

PRELIMINARY INVESTIGATIONS

In the Smithtown Water District, at the site of the original complaint, a time series test was run after a 4-hour period of nonuse with a first-draw value of 300 μg/1. It took about 48 seconds for the lead value to drop below the drinking water standard. In the home under construction, the first-draw lead value was 25,000 g/l and, after 80 seconds of flushing, the lead value still exceeded the drinking water standard. In a Melville office building with 23-month-old plumbing, first draw after a 71.5-hour shutdown (long weekend) was 120 g/l. The highest level (200 g/l at 1.5 minutes) was calculated to coincide with the location of lead-soldered joints within the plumbing system.

Continuing the investigation, more than 200 first-draw tests were conducted by H2M in Nassau and Suffolk counties -- a 1,200-square-mile area dependent on naturally low pH and generally soft groundwater for its water supply. There were many results above the drinking water standard. County health departments, the 13 towns in the bi-county area, and water suppliers were informed of these findings. Independent testing by the Suffolk County Water Authority, Suffolk County Health Department, Nassau County Health Department, and Town of Hempstead Water Department have confirmed H2M's findings (see Table 1).

In January 1983, a meeting was held with U.S. Environmental Protection Agency (EPA) personnel in Cincinnati, Ohio, to discuss the investigations held to date and to suggest further research focusing on the variables of age of plumbing and the pH and hardness of the water supply. The South Huntington Water District agreed to participate and a proposal for a cooperative study was submitted to EPA in March 1983. The "Lead Solder Aging Study" was approved by EPA to commence October 1, 1983.

EPA/SOUTH HUNTINGTON WATER DISTRICT COOPERATIVE STUDY

As of May 1984, 90 sites have been identified and selected for this study, the South Huntington Water District portion of the low pH sampling has been completed, and much raw data has been gathered but not yet fully analyzed. Ten homes were selected in each of nine age groups from zero to 20+ years old. These sites would be sampled three times at different pH levels: less than 6.2, 7.2, and 8.2. The homes were randomly selected to obtain a geographic distribution in the 19.4-square-mile service area of the District. The type of existing solder was verified in each home through scrapings of an exposed solder joint and testing by atomic absorption spectrophotometer. Of 95 homes so tested, only one had less than 0.50 percent lead in the solder; 67.3 percent of the homes had lead content ranging from 55 to 65 percent in the solder.

First-draw samples were tested for copper and cadmium in addition to lead. An additional sample was drawn for determination of various water quality parameters including pH. Copper values above the 1 milligram per liter (mg/l) Secondary Maximum Contaminant level (up to 7.77 mg/l at 6.9 pH and 0 amps) were found. These sites were checked for stray electric currents in the water service pipe to determine whether or not the high copper values are caused through grounding of electric systems to the water plumbing system.

TABLE 1

NASSAU COUNTY HEALTH DEPARTMENT TESTS

LOCATION	LEAD ($\mu g/l$)	pH	HARDNESS (mg/l)	% LEAD SOLDER	AGE (YEARS)
Locust Valley	17,000	7.0	41	60.3	0
Port Washington	4,400	6.8	49	61.7	1
Manorhaven	3,500	6.8	49	47.9	0
Woodbury	2,900	7.3	64	58.4	0
North Port Washington	930	7.0	49	50.3	0
North Hills	750	6.7	23	56.2	0
North Hills	530	6.7	23	60.0	0

TOWN OF HEMPSTEAD WATER DEPARTMENT TESTS

WATER DISTRICT	BUILDING AGE	TIME BEFORE FIRST DRAW	LEAD ($\mu g/l$) 0 MIN	LEAD ($\mu g/l$) 1 MIN
East Meadow	8 months	8 hours	2010	7
East Meadow	8 months	24 hours	1500	240
Uniondale	3 years	8-10 hours	1049	5
East Meadow	8 months	8-10 hours	810	5
East Meadow	8 months	24 hours	760	380
Roosevelt Field	6 months	12 hours	569	385
Roosevelt Field	6 months	12 hours	338	5
East Meadow	3 months	24-48 hours	186	174

During low pH sampling of 64 first-draw tests for cadmium, only one sample at 42.5µg/l was above the drinking water standard. Since the second sample at 10 seconds contained only 3µg/l cadmium, we assume the presence of cadmium was caused by the faucet.

FIRST-DRAW LEAD FINDINGS

Of the first-draw lead samples taken, 61.84 percent have been above the drinking water standard. The results ranged from a low of 2.0µg/l in a 1968 home at pH = 5.9, to values ranging from 500 to 1,200µg/l (pH ranges from 5.6 to 6.9) at 10 homes constructed between 1981 and 1983. However, the highest lead value (1,300µg/l) was obtained at pH = 5.9 in a 1968 home.

With only the initial findings at a low pH, there appears to be a correlation between the age of the lead solder and its ability to leach lead into the drinking water. Ignoring the first zero-second flush and allowing the first 300 milliliters (ml) of flush for the faucet's leaching of lead, the second sample at 10 seconds was compared for 75 homes. For homes constructed in 1980, 1981, 1982, and 1983, the second 125-ml sample (taken in March and April, 1984) indicated that 23 homes, or 70 percent, exceeded the 50- g/l drinking water standard, and 10 homes were less than this maximum contaminant level. For homes constructed between 1955 and 1979, only seven, or 17 percent, exceeded the drinking water standard at a low pH with 35, or 83 percent, less than this maximum contaminant level.

pH AND HARDNESS

Additional investigations have been undertaken to determine locations outside Long Island with water conditions that may be conducive to lead leaching. Research throughout the world indicates that leaching of lead is most acute in areas with low pH and soft water. This condition occurs not only on Long Island, but in many locations in New York State and throughout the nation. In New York State, 2,802 samples from 784 community water systems have been gathered as part of the Water Resources Investigation of the Chemical Quality of Water from Community Systems conducted by the U.S. Geological Survey and the New York State Department of Health. Review of this data shows many locations in New York City and throughout the state with pH and hardness values which may be conducive to lead leaching.

HEALTH EFFECTS OF LEAD

Adverse effects of lead on infants have been well documented, including anemia, colic, encephalopathy, nephropathy, and neuropathy. Reduced I.Q. has been associated with high lead levels. It has been recommended in at least two research studies of lead in drinking water that the safe value of lead for infants should be reduced from 50µg/l to 25µg/l. First-draw testing is important since young children might normally take a drink of water in the middle of the night without proper flushing. Infants might also get that lead-saturated first draw of water in their liquid concentrated formula.

LEAD SOLDER

The random sample of homes selected for the South Huntington study showed 67.3 percent of test sites have solder with a lead content between 55 and 65 percent. This tends to confirm that, during the past 20 years, the predominant solder used in home plumbing in this area was lead solder.

Tin/Antimony and Tin/Silver Solder

Alternatives to lead solder include tin/antimony solder and tin/silver solder. Recent wholesale costs per pound for these three solders in New York State have been: tin/lead, $4.50; tin/antimony, $8.00; tin/silver, $20.00. An estimate of one pound of solder per new home construction is probably high.

The melting range of tin/silver and tin/antimony solder is slightly higher than that for most tin/lead solder, 473°F for 95/5 tin/silver and 464°F for 95/5 tin/antimony, as opposed to 460°F for 40/60 tin/lead solder. Tin/antimony solder has been tested for leaching in a prior U.S. EPA/Seattle study which determined that the maximum leaching of antimony was $3.7\mu g/l$ after 27 hours of standing. The U.S. EPA/South Huntington study found less than $4\mu g/l$ leaching of antimony after overnight non-use at a low pH.

Legislative Impacts of the Research

In New York State, the lead content of solder could be controlled in one of three ways. The first is the State Building Code, which now permits each of 931 towns and 553 villages to ban lead solder if the County Health Department determines it a health hazard. The second method would be through the State Plumbing Code, which has considered a ban on lead solder for 18 months, but has taken no action. The third avenue is through state legislation. Such legislation has been introduced, but no bill has yet been reported out of committee. Based on the research conducted to date, H2M has recommended both state legislation and local initiatives to limit lead content in solder to 0.50 percent. In monitoring for compliance, we have found a few tin/antimony solders that contain 0.30 percent and 0.35 percent lead. The Nassau County Health Department even found one with 0.50 percent lead. Based on our local findings, in order to assure compliance without undue hardship on plumbers, we recommend that state and federal legislation set the maximum lead content in solder at 0.50 percent.

On Long Island, 10 towns serving a population of 2,334,329 have already moved to amend their plumbing codes in order to ban lead solder, and some have instituted monitoring programs to test solder for its lead content in order to verify that plumbers are adhering to the new code.

CONCLUSION

Leaching of metallic solders, particularly lead solder, appears to be affected by many factors:

- pH of water.
- Plumbing workmanship.
- Hardness of water.
- Time since last use of water.
- Age of solder.
- Percentage of lead in solder.

Where these conditions are conducive to lead leaching, large numbers of consumers are exposed to high-lead, first-draw water. If all evidence points to a need to ban lead solder -- why not now?

IMPACT OF LEACHING BY PLASTIC PIPE, FITTINGS, AND JOINING COMPOUNDS

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The California Department of Housing and Community Development (DHCD) is proposing to expand the use of plastic plumbing pipe in residential construction. The principal change with regard to water quality is to allow polybutylene (PB) and chlorinated polyvinyl chloride (CPVC) pipe in hot and cold potable water supply systems inside dwellings. SRI International, under contract to the DHCD, prepared a document in March 1983 entitled "Environmental Review of Proposed Expanded Uses of Plastic Plumbing Pipe" (1). This environmental review provides an overview of existing information about the environmental impact of the new applications of plastic pipe and identifies areas where better information is needed. This presentation focuses on one part of this review, namely, the leaching of CPVC and PB plumbing.

OVERVIEW

The impact of leached chemicals can depend on either the instantaneous concentration of the chemicals in the water or the cumulative exposure to varying concentrations over time. Thus, we would ideally like to know concentrations of leachates as a detailed function of time after installation of plumbing systems. Figure 1 shows a decreasing concentration with time as the chemicals in the pipe are depleted or immobilized. Different chemicals would show more or less rapid declines over time after installation, depending on their properties and their initial distribution in the pipe.

The general pattern, however, is only a large-scale picture; many events disturb the smooth trend. Concentrations build up when water stands in the pipe for a period of time ("dwell time"), for example, overnight or during a vacation. When the system is flushed, concentrations drop to the background levels of the incoming water supply. The variation over a day or two might look something like that in Figure 2.

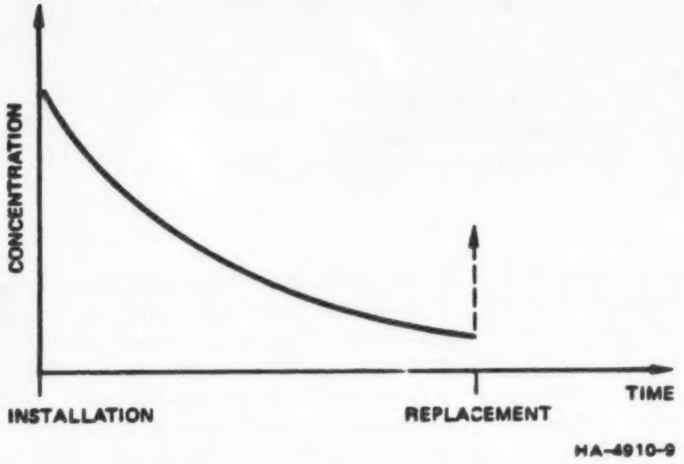

FIGURE 1 LONG-TERM PATTERN OF DECLINE IN CONCENTRATION

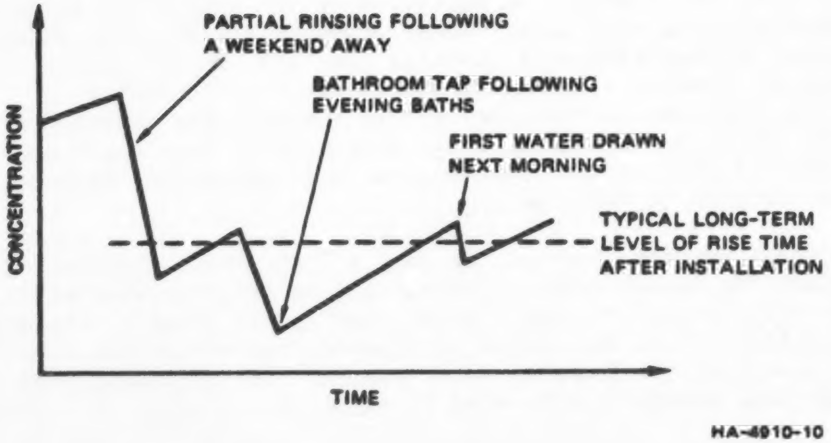

FIGURE 2 SHORT-TERM VARIATIONS IN CONCENTRATION

LEACHING MODELS

If water stands in a pipe, the concentration of a specific chemical in the water will be determined by the leaching rate, or flux, of the chemical integrated over time. The leaching rate, in turn, will be determined by the amount and distribution of the chemical in the pipe, the diffusion of the chemical in the pipe and in the water, the equilibrium partitioning of the chemical between the pipe and the water, and the diffusion of the leachate out of the pipe into the air.

The differential equations that describe mass transfer in the pipe and in the water are given by Fick's second law of diffusion. The solution of these equations depends on the initial and boundary conditions for the pipe/water system. Two relatively simple cases for pipe leaching appear to be reasonable. In the first case, a surface film of leachate covers the inner surface of the pipe and diffuses into an initially pure water phase. In the second case, the leachate is initially distributed uniformly in the pipe and diffuses into an initially pure water phase.

In Model 1 the leachate is concentrated at the pipe/water interface. The leachate equilibrates with the water relatively rapidly, and the amount of leachate in the water depends on the equilibrium partitioning of the leachate between the surface film and the water (described by H' in Figure 3) and on the number of equilibrium dwell periods that water has stood in the pipe. Figure 3 simply shows that as H' decreases (where the leachate becomes more soluble in water and less soluble in the pipe material), the concentration in the dwell water decreases more rapidly with the number of equilibrium dwell periods.

In Model 2 the leachate is initially uniformly distributed in the pipe. Equilibrium is not attained during a dwell period, and the amount of leachate in the water in a given dwell period will be diffusion controlled and over a long elapsed time will diminish with a square-root-of-time dependence. Figure 4 shows the concentration versus time profile for this model, assuming daily sampling and the concentration in units of the initial sample concentration.

Unfortunately, few data exist on pipe/water partitioning coefficients or plastic pipe diffusion coefficients and, because these coefficients are likely to be very sensitive to specific chemical/pipe interactions, they are difficult to predict. Although these models cannot be used to predict leaching from plastic pipes, they are useful for evaluating and understanding experimental data. This is particularly important for evaluating CPVC leaching data because of the complex composition of CPVC and the use of solvent cement to join the piping.

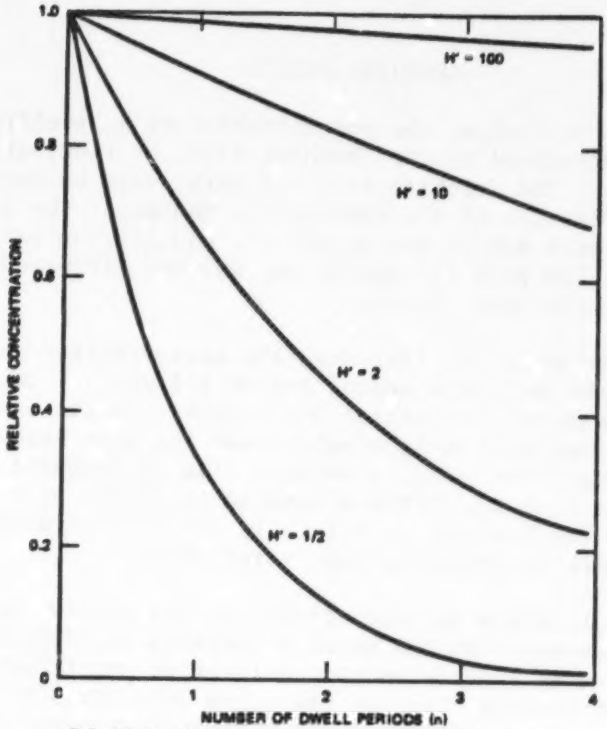

FIGURE 3 CONCENTRATION OF LEACHATE IN WATER ACCORDING TO MODEL 1

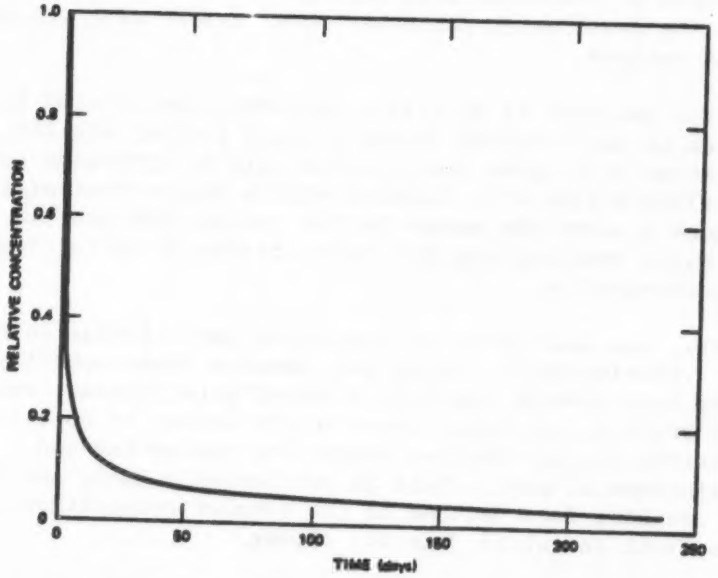

FIGURE 4 CONCENTRATION VERSUS TIME PROFILE FOR MODEL 1

Assume daily sampling and concentration in units of initial sample concentration.

PLASTIC PIPE COMPOSITION

The composition of plastic pipes should be known to determine possible leachates. Nonproprietary specifications supplied by manufacturers of plastic pipe and the National Sanitation Foundation (2) are summarized in Table 1. PB is composed primarily of the resin polymer and contains small amounts of pigments (such as titanium dioxide, carbon black, or talc) and a small amount of antioxidant (such as Irganox 1010). The composition of CPVC is more complex and requires a solvent cement for joining pipes. Potential health problems associated with toxic chemicals leached from joined CPVC pipes are accordingly more difficult to assess than potential water-quality problems with PB. Therefore, most of the remainder of this presentation focuses on CPVC leaching.

QUALITY ASSURANCE

There are several important reasons for closely examining the quality of plastic pipe leaching data:

1. The composition of pipe leachate water is likely to be a complex mixture (particularly for CPVC) of organic compounds in very dilute concentrations.

2. Many of the potential leachates of plastic pipe are commonly found in drinking water at measurable background concentrations.

3. Much of the work on plastic pipe leaching has been performed by parties that had institutional interest in the question of pipe water quality.

Excellent QA guidelines for plastic pipe leaching studies are detailed in the Interim Report by the National Sanitation Foundation entitled "Proposed Organohalide Leachate Testing Protocol for Plastic Piping."

CPVC LEACHING

The most important reports to date on CPVC leachability are those by James M. Montgomery (3) and Boettner et al. (4).

James M. Montgomery, Consulting Engineers, Inc., under contract to the California Department of Health Services, measured the water leachability of PVC and CPVC pipes. The testing protocol consisted of static, simulation, and kinetic tests. The static test was designed to estimate the concentrations of chemicals in water expected during initial occupancy. The kinetic test was designed to estimate the rate of leaching so that the concentration of the chemical in the water could be predicted as a function of time. The simulation test was designed to estimate leachability during typical home use.

TABLE 1

COMPONENTS OF PLASTIC PIPE SYSTEMS

PRODUCT	FUNCTION	PB	PERCENT	CPVC	PERCENT
Pipe and fittings	Resin	Poly(butene-1)	>98	Chlorinated PVC	>80
	Impact modifiers	None		ABS Methyl-methacrylate-butadiene-styrene-alpha-methyl styrene	>3 <15
	Stabilizers/ antioxidants	Irganox 1010	<0.5	Organotins	<3.5
	Lubricants	None		Oxidized polyethylene wax	<1.5
	Pigments/fillers UV stabilizers	Titanium dioxide Carbon black Talc	<2.0 <0.5 <2.0	Titanium dioxide Carbon black Others	<5.0 <0.05 <0.1
Solvent Cement	Solvents	None		Tetrahydrofuran Cyclohexanone 2-Butanone (methyl ethyl ketone) N,N-dimethyl formamide	80-90
	Resin/compound			CPVC or CPVC pipe compound	<20
	Pigments			Titanium dioxide Carbon black Others	<0.5
Primers	Solvents and pigments	None		Same as for solvent cement	

The major limitations of this study were a lack of replicate experiments and the consequent inability to quantify the statistical validity of the data. In spite of these and other limitations, the Montgomery report does give a semiquantitative picture of CPVC leaching.

Data compiled from the static and simulation tests indicate that the following organic chemicals were consistently found in significant concentrations in pipe water:

CEMENT SOLVENTS	VOLATILE ORGANICS
MEK	Dichloromethane
THF	Carbon tetrachloride
Cyclohexanone	Tetrachloroethene
DMF	Trichloroethene
	Toluene

The cement solvents were found in the parts-per-million range, but the amounts found appear to diminish rapidly, as expected, with rinsing. The volatile organics (except toluene) were typically found in the pipe water in the 1- to 10-ppb range for systems that approximated normal initial use of plumbing systems. Toluene was typically detected under 1 ppb. Chloroform may leach from the pipe; however, the data are inconclusive. Two of the tests found chloroform at levels no different from those in controls (kinetic and simulation), but it was found at levels marginally significantly different from those in controls in the static tests.

For the static tests, no correlation of concentration with dwell time or elapsed time was observed for the low-molecular-weight halogenated organics that were found in significant amounts. The cement solvents, however, show a definite decrease in concentration during the first few rinses of the cemented pipe. The absolute magnitude of these concentrations is probably unrealistic, even for initial use of a plumbing system, because of the low number of void volume rinses.

For the kinetic tests, no significant correlations between dwell time and concentration could be deduced for the volatile organics. Conversely, the concentrations of the cement solvents appeared to increase with increasing dwell time up to a limiting equilibrium value. Moreover, these concentrations fell significantly during the refill dwell kinetic experiments.

The work of Boettner et al. (1981) was initiated to develop an analytical method for detecting organotin stabilizers in water. In the process, useful information on CPVC leachability was obtained.

This report confirmed the findings of the Montgomery report on the leachability of cement solvents. High initial concentrations of these solvents were found in the pipe water and these concentrations decreased with elapsed time. Boettner et al. also detected the presence of organotin leachates in CPVC pipe water. The concentrations of these leachates were initially in the 0.5- to 3-ppb range for 1-day dwell periods, but fell rapidly to less than 0.1 ppb per day after 3 weeks elapsed time.

It is interesting to note that the concentrations of the organotin leachates appeared to diminish in a biphasic manner with time; that is, the concentrations diminished, then increased, then diminished again. This biphasic behavior suggests two types of leaching in cement-joined pipes. The initial leaching of organotins occurs from areas of the pipe where solvent cement has not been applied. This leaching diminishes rapidly as the surface concentration is depleted. In the areas where solvent cement has been applied, there is no organotin present initially, but within a few days, organotin species begin to diffuse through the cement/pipe surface layer into the water, and the leachate concentration correspondingly rises.

These data suggest a possible explanation for a lack of correlation between leachate concentrations of noncement solvents and time that was described in the 1980 Montgomery report. If solvent cements were applied in differing thicknesses to the joints of the test systems, it would be expected that the leaching of pipe constituents through the cement to the water would be retarded in varying degrees. Thus, while the leaching rate in one part of the system may have been diminishing, the leaching rate in another part of the system may have been increasing. For a plumbing system with several joints, the variability of the leaching rate with elapsed time over a period of several weeks may well have been sporadic, as observed.

SUMMARY OF PLASTIC PIPE LEACHING DATA

CPVC leaching data indicate that:

- Pipe cement solvents (MEK, THF, cyclohexanone, and DMF) are initially leached at very high concentrations, but these concentrations diminish rapidly with repeated flushing.

- Low-molecular-weight chlorinated organics (dichloromethane, carbon tetrachloride, tetrachloroethene, and trichloroethene) are leached in the low (1-10) ppb concentration range during initial dwell periods. The lack of correlation of the concentrations of these leachates with dwell time or elapsed time is probably caused by the relative uncertainty of the measured values (which were typically within a factor of 5 of control values) and by the cumulative effect of leaching of these organics at different rates from areas covered or not covered with solvent cement.

- Chloroform is a possible leachate. More work is required on chloroform leaching and on the leaching of chemicals other than the dominant solvents from the solvent cements.

POLYBUTYLENE LEACHING

The leachability studies of PB were generally of lower quality than those of CPVC. However, a study by Shell (5) indicated the presence of Irganox 1010 derivatives in leachate waters. Irganox 1010 is an antioxidant that is present in PB at less than 0.5%.

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NSF STANDARD AND CERTIFICATION PROGRAM FOR PLASTICS PIPE: STANDARD 14

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The National Sanitation Foundation (NSF) is a private, not-for-profit corporation, chartered in 1944 under Michigan law. Its mission is to develop and administer programs relating to public health and the environment in areas of services, research, and education. Through its headquarters and laboratories in Ann Arbor, Michigan, a wastewater equipment testing facility in Chelsea, Michigan, and regional offices in or near Los Angeles (Upland) and Sacramento (Davis), California; Ann Arbor, Michigan; Philadelphia (Chalfont), Pennsylvania; Atlanta, Georgia; and Dover, England, NSF's programs and services reach throughout the United States and into 25 foreign countries.

For operational purposes, programs are grouped into Listing, Certification, and Assessment Services. Listing Services programs are those for which there is an NSF standard, authorization to display the appropriate seal or logo, and a published product Listing. Certification Services programs involve standards other than NSF's official regulations, or specifications. They include authorization to display the certification mark, and a published product Registry. All other programs and special studies are provided through Assessment Services. A controlled use report is provided for special studies; the identity mark is the company logo. Each of these programs is available for domestic and international application.

A highly qualified professional and technical staff — engineers, chemists, microbiologists, and environmental scientists — is retained by NSF in state-of-the-art facilities. Consulting faculty from the University of Michigan are retained for toxicological, radiological, and other expertise, as required. Recent capital acquisitions focus on laboratory and information processing resources intended to optimize quality and timeliness of all operations. A $3.25 million laboratory expansion program (current) attests to the high performance and growth objectives to which the Trustees and staff are fully committed.

Plastics piping system components have been tested at NSF since 1955, first in a comprehensive special study of leachate and toxicological testing (1), then under the provisions of Standard 14, Plastic Piping System Components and Related Materials. This Standard includes products for potable water; drain, waste, and vent; and other plumbing systems applications.

Ingredients used in products listed for potable water must comply with rigid acceptance and qualification procedures prior to listing. These requirements are summarized in Figure 1.

With an application for listing, a manufacturer provides complete, detailed chemical identity of all ingredients in the formulation. This information is reviewed by staff, and held under terms of confidential disclosure. For ingredients generally regarded by the Food and Drug Administration (FDA) as safe, or sanctioned previously for food contact, e.g., listed in Title 21, Code of Federal Regulations (21CFR), no further toxicological testing is usually required. For nonsanctioned ingredients, Ames and animal feeding studies must be provided. The animal data must include established no-effect, effect, and intermediate levels of the proposed ingredient, using protocols and a testing laboratory accepted by NSF in advance of the testing.

Chemical leachate testing is required for all proposed new ingredients, using pipe and compound formulated to contain the ingredient at two times the level proposed for maximum use. Chemical leachate (extraction) testing for inorganic contaminants is performed consistent with the testing protocol in Standard 14; i.e., exposure to "formulated water" at pH 5.0 ± 0.2 at 37 degrees (°C) for periods of 24, 24, and 72 hours. (Cold-water end-use applications are assumed; for hot-water applications, exposures are 1 hr at 82° C, 1 hr at 82° C, and 72 hr at 37° C.) Fresh water is added following each of the 24-hour exposures, providing data for three separate extractions. The first exposure is assumed to simulate worst- case end use, where the user would ingest the first, very aggressive water drawn from a new installation; the third exposure represents water which could be ingested as the first draw of water left standing over a weekend. The protocol for organic chemical leachate testing is similar except that pH 8.0 ± 0.15 is used for the exposure.

The chemical parameters monitored and their maximum permissible limits (MPLs) are shown in Figure 2. (Currently, five volatile organic compounds proposed by EPA for regulation are also being monitored to acquire a data base. They are CCl_4; TCE; PCE; 1,2-dichloroethane; and 1,1,1-trichloroethane.) For proposed new ingredients, the MPL for the first exposure (MPL-1) is set at ten times the established, third-exposure MPL (MPL-3). MPL-3 is equivalent to maximum contaminant levels (MCLs) in the National Interim Primary Drinking Water Regulations (NIPDWR) for all regulated chemicals included in Standard 14. By policy, all chemicals regulated by NIPDWR are included in Standard 14 when pertinent to the listed products.

Acceptance[1] *(New or Generically Similar Ingredient)*	**Qualification**[1] *(New Product or Change in Formulation)*	**Monitoring**[2]
Disclosure statement with complete chemical identity		
Product and compound tested at 2 X maximum recommended use level	Product and compound tested at maximum use level	
Chemical leachate testing[3] 1st exposure ≤10 X MPL[4] 3rd exposure ≤MPL[4]	Chemical leachate testing[3] 1st exposure ≤10 X MPL[4] 3rd exposure ≤MPL[4]	Chemical extraction testing[3] 3rd exposure ≤MPL[4]
	Performance testing HDS ASTM[4]	Performance testing HDS ASTM[4]
FDA/21CFR If no, Ames test and 90-day feeding study at effect, no effect, and intermediate levels		

[1] Samples submitted by applicant.
[2] Samples collected by regional staff.
[3] RVCM ≤MPL is also required for PVC and CPVC pipe and fittings.
[4] Refers to all parameters in Standard 14.

Figure 1. Summary of requirements for products listed under Standard 14.

Parameter	MPL-3 (ppm)
Antimony	0.05
Arsenic	0.05
Barium	1.0
Cadmium	0.01
Chromium	0.05
Lead	0.05
Mercury	0.002
Phenolic Substances	0.05
RVCM (in finished product)	10.0
Selenium	0.01
Tin	0.05
TTHMs	0.01

Figure 2. Chemical parameters in Standard 14.

A special test protocol has been developed and validated for organics leachate testing. Nineteen samples of polyvinylchloride (PVC) and chlorinated polyvinylchloride (CPVC) were used for validation testing. To date, none of the data suggests that the listed products contribute significant levels of trihalomethanes to contacted water.

To confirm compatibility with other ingredients in a product recipe, an accepted new ingredient must also be "qualified" by additional chemical leachate testing. Products formulated by the ingredient user (pipe, fittings, or appurtenance manufacturer) at the maximum proposed use level are tested in accordance with the procedure described for acceptance testing.

Following acceptance of an ingredient and qualification of product, listing is authorized. The appropriate logo is then displayed on the product; i.e., NSF-pw, -wc, for potable water/well casing applications; NSF-dwv, -tubular, for drain, waste, and vent/continuous waste systems; NSF-cw, for corrosive wastes; NSF-sewer, for sewer main applications.

Standard 14, adopted in 1965, is revised and updated on a continuing basis. In 1978, a requirement for residual vinyl chloride monomer (RVCM) was added. By modeling and leachate testing, it was established that levels to 10 parts per million (ppm) RVCM in the wall of pipe or fittings would not leach detectable levels of the monomer to water exposed to product (where "detection" is 2 ppb). Results of RVCM monitoring experience show that none of the 460 samples tested in 1982 or 472 samples tested in 1983 exceeded the established MPL of 10 ppm.

From the outset, standards development at NSF has included representatives at all levels of government, the affected industry, and users of the subject products or services. Typically, the request for a standard may originate with any of the three sectors. Interest and commitment are established in an exploratory meeting. A small task committee is appointed to draft the document. The draft is reviewed and revised or accepted by the Joint Committee (JC), where each sector -- regulatory, industry, and user -- has voting representation. The Joint Committee proposes the standard to the Council of Public Health Consultants, a group of 36 public health professionals with no industry representation. The Council recommends a standard to the Board of Trustees, where final adoption occurs.

All NSF standards have a requirement for periodic review at intervals not to exceed five years. The formal, ongoing review and revision or reaffirmation process is accomplished through established Joint Committee policies. All voting is in compliance with procedures described in the Office of Management and Budget (OMB) Circular A119 (2).

Three annual inspections are required for all plastics production facilities included in the listing. These are minimums and apply to foreign and domestic sites. Nonconformance and other problems result in additional inspections. At the plant, products in production and inventory are checked to verify consistency with previous design and testing records. Use of accepted ingredients or compounds and in-plant quality assurance are verified; and selected evaluations may be performed (e.g., dimensioning products). Seven hundred and eleven (711) inspections are projected for 1984. Violations identified either in testing or inspection result in various actions, ranging from corrective measures to delisting.

There are three general categories of regulation -- official, self-regulation, and third-party. Third-party programs have established credibility world-wide. They effectively and appropriately place cost burdens with the private sector. Their objectivity and long-term success are a matter of record and a source of pride! We look forward to expanded opportunities with plastics plumbing systems components and related products through voluntary consensus standards and third-party certification programs like NSF Standard 14.

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EVALUATION OF THE PERMEATION OF ORGANIC SOLVENTS THROUGH GASKETED JOINTED AND UNJOINTED POLY(VINYL CHLORIDE), ASBESTOS CEMENT, AND DUCTILE IRON WATER PIPES

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SUMMARY*

Phase one of the Vinyl Institute's research program, "Evaluation of the Permeation of Organic Solvents through Gasketed Jointed and Unjointed Poly(vinyl chloride), Asbestos Cement, and Ductile Iron Water Pipes," has been completed. Phase one involved the exposure of commercially available 4-inch water pipe joints to three neat organic solvent environments (toluene, hexane, and 1,1,1-trichloroethane) for a period of 6 weeks. Each pipe specimen contained demineralized water under a pressure of 40 pounds per square inch gauge (psig) and throughout the 6-week exposure period, samples of water were removed from each pipe and analyzed for traces of the appropriate organic liquid.

The objective of this program was to study when and how permeation of selected solvents occurs through the jointed and unjointed pipes and to develop a hypothesis for the mechanism of permeation. The tests results indicate that the mechanism for fastest breakthrough (permeation) is through the gasketing material. The unjointed pipe showed slower permeation or no permeation compared to the jointed pipe. When permeation

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*Copies of original work are available on request to: Dr. Roy T. Gottesman, Executive Director, Vinyl Institute, 355 Lexington Avenue, New York, New York 10017.

did occur with the jointed pipe, it happened much earlier than with the straight unjointed pipe. Another mechanism for breakthrough is based on the composition of the pipe. The moreporous asbestos/cement unjointed pipe showed early permeation with toluene and 1,1,1-trichloroethane, and the unjointed PVC pipe swelled to permeation with toluene after day 37 of the 42-day test.

The initial work was performed under "worst case model" conditions. The breakthrough of neat solvents in the jointed test specimens indicates that the joints of all three materials are susceptible to permeation. The second phase of the program, expsoure to aqueous solutions of the same organic solvents, appears to be warranted in order to determine permeation under more realistic conditions. Consideration should be given in characterizing the rubber compounds used in the gaskets. Differences in the gaskets used with each type of pipe may explain the apparent differences in permeation, particularly with regard to hexane.

CONCLUSIONS

1. Permeation of neat solvents is related to type of solvent, type of pipe, whether the pipe is jointed or unjointed, and time of exposure.

2. For all the organic solvent/pipe combinations investigated, the jointed pipes showed organic solvent breakthrough (permeation). The sole exception was the ductile iron/hexane, although the jointed ductile iron pipe demonstrated permeation with toluene and 1,1,1-trichloroethane.

3. The unjointed pipe showed slower permeation or no permeation compared to the jointed pipe. Also, when permeation did occur with the jointed pipe it happened earlier than with the straight unjointed pipe.

4. The permeation data indicate that the mechanism for fastest breakthrough is through the gasketing material. The gasketing material used to seal the jointed pipes is more susceptible to organic solvent (toluene, hexane, and 1,1,1-trichloroethane) permeation than is the pipe material.

5. Another mechanism for permeation is based on the composition of the pipe. The more porous asbestos/cement unjointed pipe showed early permeation by toluene and 1,1,1-trichloroethane. The unjointed PVC slowly softened to point of permeation with toluene between sampling days 37 and 41, and the unjointed iron pipe did not show permeation.

6. The order of aggressiveness (i.e., attack on the pipes and gaskets) for the organic solvents from greatest to least is toluene > 1,1,1-trichloroethane > hexane.

7. Toluene permeated all jointed pipe sections. Toluene did not permeate the ductile iron unjointed pipe, and the PVC unjointed pipe showed breakthrough after day 37 of the 42-day test.

8. 1,1,1-Trichloroethane permeated all jointed pipe sections. It did not permeate the PVC straight pipe or the iron straight pipe. The asbestos straight pipe showed permeation at about 2 weeks.

9. Hexane permeated PVC jointed pipe and asbestos/cement jointed pipe. Iron jointed pipe and all straight pipes showed no permeation. The presence of a dark oily residue in the jointed PVC pipe substantiates the conclusion that the gasketing material has been attacked. The absence of permeation with jointed iron pipe suggests that this gasket is not solvated by hexane, whereas it was attacked by toluene and 1,1,1-trichlorethane in parallel tests.

10. Entry of organic solvent into the demineralized water against 40 psig internal pressure is corroborating evidence that the mechanism is permeation through gasketing material or pipe and not hydraulic flow. Constant internal pressure does not exclude contamination by permeation.

TREATMENT OR WATER QUALITY ADJUSTMENT TO ATTAIN MCLs IN METALLIC POTABLE WATER PLUMBING SYSTEMS

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INTRODUCTION

Virtually all of the common household or building plumbing materials — copper tubing, galvanized steel, lead pipe, brass fittings, and tin/lead solder — will oxidize and dissolve to some extent in potable waters. The byproducts of these corrosion reactions can be of concern because of aesthetic or toxicological reasons; hence, the development (1,2) of maximum contaminant levels (MCL) or of secondary (2) maximum contaminant levels (SMCL) for lead, cadmium, copper, zinc, and iron. Additionally, corrosion is economically costly, because of decreased service lifetimes of piping materials, loss of water during distribution, and decreases of hydraulic efficiency.

Traditionally, corrosion control measures taken by water utilities have been aimed at preventing tuberculation and perforation of cast-iron distribution mains, eliminating "red water" complaints, and protecting dissolution of cement-mortar-lined or asbestos-cement pipe. Treatment processes designed to alleviate some or all of these distribution system problems may or may not effectively limit the corrosion of the different types of metallic materials used in the service lines and interior systems of buildings and dwellings.

The purpose of this paper is to examine the impact of several common treatment approaches on the formation of corrosion byproducts from common building plumbing materials. The treatment approaches covered in this paper will be: calcium carbonate saturation, pH adjustment, pH plus carbonate adjustment, orthophosphate addition, polyphosphate addition, and silicate addition. First, however, a background will be developed to aid in the understanding of the feasibility of different corrosion control approaches.

SOLUBILITY AND MASS-TRANSPORT PROCESSES

Unlike most distribution system mains, household and building systems frequently have large sections of piping in which the water can be stagnant for hours. During these long periods of standing, corrosion reactions can continue to add byproducts to the water until a state of solubility equilibrium is nearly or actually attained. Thus, the metal levels observed in the water are initially governed by the mass transport of oxidizing or solubilizing agents to the pipe surface, and of the corrosion products away from the surface. The upper-limiting case, from a dissolved byproduct standpoint, is that ultimately provided by the solubility equilibria of the surface pipe material in the water. Physical factors, such as nonadherence of the corrosion product film or the dislodging of scales by normal turbulent flow, can add particulate metal species to the water, increasing the observed "total" metal concentration. Also, corrosion reactions can continue, even if the solubility equilibrium is attained.

Clearly, there are numerous tradeoffs in corrosion control programs. For instance, the minimization of metal levels in order to attain MCLs may not result in the formation of an effective barrier to continuing metal attack, shortening the lifetime of the plumbing material. It may merely convert the metal into an adherent corrosion product while surface attack and/or pitting continues. Alternatively, an absence of bulky corrosion products and tubercles on iron lines brought about by treatment chemicals, such as polyphosphates, might result in increased levels of soluble iron through complexation.

In general, the strategy of corrosion control through water quality adjustment involves interference with at least one link of the chain of interconnected anodic and cathodic corrosion cell reactions (4). Ordinarily, this consists of the formation of a "barrier" of a "passivating film" that both limits the transport of the metallic species into solution (mostly through solubility limitation), and limits the diffusion of the oxidizing agents (normally dissolved oxygen or chlorine species) to the pipe surface. These complicated couplings of redox and solubility reactions, plus the differences in relative rates of the reactions, prevent simple relationships between corrosion rates determined from pipe coupon or insert data and solubility levels from being developed.

An example of the role of mass transport in governing the metal level in nonequilibrium systems has been elegantly developed by Kuch and Wagner (5) for lead. The approach is generally suitable for other types of pipe, as well. These authors show that the level of lead in a water undergoing turbulent flow can be predicted by knowing the lengths and diameters of the lead pipes, the observed (or computed) concentration of lead at solubility equilibrium, the volume flow rate of the water, the water temperature, and the diffusion coefficient of the dissolved species. For water under stagnating conditions, the parameters that need to be known to compute the lead level after a given stagnation time are: the diameter of the pipe, the diffusion coefficient (approximated by that for Pb^{2+}), the maximum equilibrium lead concentration, and the lead concentration during flushing (computed from the previous model). In hard waters, the mass transfer coefficient may also need to be included.

FORMATION OF PASSIVATING FILMS

Because the *in situ* formation of tight, adherent films that are impervious to ionic or oxidant migration is virtually impossible, a discussion of the solids that can precipitate in pipes and produce a limit for metal solubility is in order. Only common building plumbing materials — lead, copper, new galvanized steel, and brass — will be considered here.

Table 1 gives a list of solid corrosion products that have been found that are likely to be significant in controlling the solubility of the different pipe or coating metals. Each metal behaves uniquely, and these solids are largely responsible for determining whether or not a corrosion control technique will work. Other deposits have been reported, but systematic and comprehensive surveys in many water qualities at different temperatures have not been done. Solids containing sulfate and chloride are often common in saline waters, waters with a high ionic strength, or in the presence of pits in copper tubing (6). Other deposits may also locally form, but they may not act as solubility controls.

Detailed research has not been performed to identify the films of corrosion products or inhibitor precipitates formed on tin/lead solder or brass fittings under different water quality conditions. Until that time, we must assume formation of the same products as would be present on pipes of similar material.

The relationship of passivating film formation to water quality adjustment and inhibitor dosage will be covered for galvanized steel (zinc), copper, and lead in the next section. To assist in predicting orthophosphate inhibitor effectiveness and the effect of pH and alkalinity (through the inorganic carbonate content), solubility calculations were performed in a similar manner to those reported previously for lead (7-10) and zinc (10-11). A new computer program was created for calculation of copper (II) solubility. The equilibrium constants used are reported in Tables 2 and 3. Considerable uncertainty exists for much of the thermodynamic data, and all computations were restricted to 25°C because temperature effects on the equilibrium constants are largely unexplored. An ionic strength of 0.0005 moles per liter (mol/L) was assumed as a general approximation. The pH interval of 7 to 11 was considered, as well as total inorganic carbonate (TIC) concentrations of from 5 to 500 milligrams calcium carbonate per liter (mg $CaCO_3$/L) (0.05-5.0 mmole C/L). Only orthophosphate, hydroxide, and carbonate solids with a documented history of occurrence in plumbing systems were included; hence,

Table 1. Scale Minerals That May Be Important in Limiting the Solubility of the Indicated Metals and Metallic Materials in Most Potable Water Systems

Galvanized Steel Pipe

Basic Zinc Carbonate (hydrozincite, $Zn_5(OH)_6(CO_3)_2$)
Zinc Hydroxide, $Zn(OH)_2$, α-, β-, δ-, and ε- forms
α-Hopeite, $Zn_3(PO_4)_2 \cdot 4H_2O$
Zinc Oxide (Franklinite), ZnO or $ZnFe_2O_4$
Hemimorphite, $Zn_4Si_2O_7(OH)_2 \cdot H_2O$ (hot water systems)

Copper Pipe

Cuprite, Cu_2O
Tenorite, CuO
Basic Copper Carbonate (Malachite), $Cu_2(OH)_2CO_3$
$Cu_3(PO_4)_2 \cdot 4H_2O$
Brochantite, $Cu_4(OH)_6SO_4$
Atacamite, $Cu_2(OH)_2Cl$

Lead Pipe

Basic Lead Carbonate (hydrocerussite), $Pb_3(CO_3)_2(OH)_2$
Lead Carbonate (cerussite), $PbCO_3$
Hydroxypyromorphite, $Pb_5(PO_4)_3OH$
Plattnerite, PbO_2

Table 2. Reactions and Log Equilibrium Constants (β) at 25°C
and I = 0 mol/L Species Considered in Solubility Diagram Construction
M = Pb, Cu or Zn. All constants are for I = 0 and 25°C

			log β		
			Pb	Zn	Cu
$M^{2+} + H_2O$	$\leftrightarrow$	$MOH^+ + H^+$	-7.23	-8.96	-7.93
$M^{2+} + 2H_2O$	$\leftrightarrow$	$M(OH)_2^\circ + 2H^+$	-16.93	-16.9	-16.23
$M^{2+} + 3H_2O$	$\leftrightarrow$	$M(OH)_3^- + 3H^+$	-28.10	-28.4	-26.9
$M^{2+} + 4H_2O$	$\leftrightarrow$	$M(OH)_4^{2-} + 4H^+$	-39.7	-41.2	-39.6
$2M^{2+} + H_2O$	$\leftrightarrow$	$M_2OH^{3+} + H^+$	-6.36	-9.0	--
$2M^{2+} + 2H_2O$	$\leftrightarrow$	$M_2(OH)_2^{2+} + 2H^+$	--	--	-11.21
$3M^{2+} + 4H_2O$	$\leftrightarrow$	$M_3(OH)_4^{2+} + 4H^+$	-23.88	--	-22.05
$4M^{2+} + 4H_2O$	$\leftrightarrow$	$M_4(OH)_4^{4+} + 4H$	-20.88	--	--
$6M^{2+} + 8H_2O$	$\leftrightarrow$	$M_6(OH)_8^{4+} + 8H^+$	-43.61	--	--
$M^{2+} + CO_3^{2-} + H_2O$	$\leftrightarrow$	$MHCO_3^+$	--	11.73	12.41
$M^{2+} + CO_3^{2-}$	$\leftrightarrow$	MCO_3°	7.1	5.2	6.8
$M^{2+} + 2CO_3^{2-}$	$\leftrightarrow$	$M(CO_3)_2^{2-}$	10.3	7.5	9.8
$M^{2+} + PO_4^{3-} + H^+$	$\leftrightarrow$	$MHPO_4^\circ$	15.45	15.66	16.36
$M^{2+} + PO_4^{3-} + 2H^+$	$\leftrightarrow$	$MH_2PO_4^+$	21.1	21.16	21.33

Table 3. Equilibrium Constants at 25°C and I = 0 mol/L for the Solids Considered in the Exploratory Solubility Calculations

			log K
$Pb(OH)_2(s) + 2H^+$	$\leftrightarrow$	$Pb^{2+} + 2H_2O$	13.07
$PbCO_3(s)$	$\leftrightarrow$	$Pb^{2+} + CO_3^{2-}$	-13.13
$Pb_3(CO_3)_2(OH)_2(s) + 2H^+$	$\leftrightarrow$	$3Pb^{2+} + 2CO_3^{2-} + 2H_2O$	-18.0
$Pb_5(PO_4)_3OH(s) + H^+$	$\leftrightarrow$	$5Pb^{2+} + 3PO_4^{3-} + H_2O$	-62.8
$CuO(s) + 2H^+$	$\leftrightarrow$	$Cu^{2+} + H_2O$	-7.62
$Cu(OH)_2(s) + 2H^+$	$\leftrightarrow$	$Cu^{2+} + 2H_2O$	-8.64
$Cu_2(OH)_2CO_3(s) + 2H^+$	$\leftrightarrow$	$2Cu^{2+} + CO_3^{2-} + 2H_2O$	-5.18
$CuCO_3(s)$	$\leftrightarrow$	$Cu^{2+} + CO_3^{2-}$	9.63
$Cu_3(PO_4)_2 \cdot 2H_2O(s)$	$\leftrightarrow$	$3Cu^{2+} + 2PO_4^{3-} + 2H_2O$	-35.12
ε-$Zn(OH)_2(s) + 2H^+$	$\leftrightarrow$	$Zn^{2+} + 2H_2O$	11.54
$ZnCO_3(s)$	$\leftrightarrow$	$Zn^{2+} + CO_3^{2-}$	-10.00
$Zn_5(OH)_6(CO_3)_2(s) + 6H^+$	$\leftrightarrow$	$5Zn^{2+} + 2CO_3^{2-} + 6H_2O$	9.65
$Zn_3(PO_4)_2 \cdot 4H_2O(s)$	$\leftrightarrow$	$3Zn^{2+} + 2PO_4^{3-} + 4H_2O$	-35.3

the absence of solids such as $Pb_3(PO_4)_2$ and $Pb_3(OH)_5Cl$. An exception was $Cu_3(PO_4)_2 \cdot 2H_2O$, which was the only copper orthophosphate for which data was available.

The results of some of the computations are presented in Figures 1 through 5, which will help show trends in solubility behavior of three of the trace metals of interest. Even though computations went up to 2 mg PO_4/L, the diagrams are shown only for an orthophosphate concentration of 0.5 mg PO_4/L, which is a common dosage. For copper (II), no precipitation of orthophosphate was predicted. These diagrams show "contour lines" for the metal solubility, as both pH and TIC are varied. A three-dimensional version of Figure 1 for lead (II) is shown in Figure 6, for comparison. The units of "log mg/L" were chosen to produce smooth contour line intervals and good detail in the diagrams. Reference will be made to these figures in the following section.

TREATMENT APPROACHES

CALCIUM CARBONATE SATURATION

This is the approach traditionally followed by utilities with hard and moderately hard water supplies. Also, many utilities who use lime softening for clarification also use this strategy. Monitoring the calcium carbonate saturation state was also included as one of the requirements of the U.S. EPA "Corrosivity" regulation (1). Many expositions on the rationale for $CaCO_3$ saturation are available, but the primary intent can be summarized by saying that the objective has been to prevent tuberculation and "red water" in iron distribution mains by covering the pipe with a thin and adherent layer of calcium carbonate. However, research by Stumm in the 1950s and 1960s (12, 13), and more recently by primarily German scientists (14, 15), indicates that the effective corrosion control mechanism involves the formation of a dense siderite ($FeCO_3$) scale layer, and is also related to the buffer intensity of the water and the Fe(II)/Fe(III) ratios in the pipe deposits.

Numerous indices are available for the estimation of the calcium carbonate saturation state, and they have been thoroughly reviewed elsewhere (16-18). The concept of using a calcium carbonate film to "seal" the surface of a copper, lead, or galvanized pipe in household or building systems in order to prevent metal leaching has been widely assumed to have been validated. However, virtually no research has been published to define the water quality conditions (i.e., pH, temperature, calcium, and carbonate concentrations) or the time necessary to form the film, or to examine the metal leaching behavior while film formation is in progress. For zinc and copper, Figures 3 and 5 indicate that concentrations below the SMCLs should remain easily attainable at pH values above 7.5 for most conceivable TIC levels, in the absence of complete surface coverage by the calcium carbonate deposit. Obviously, the thickness and homogeneity of the

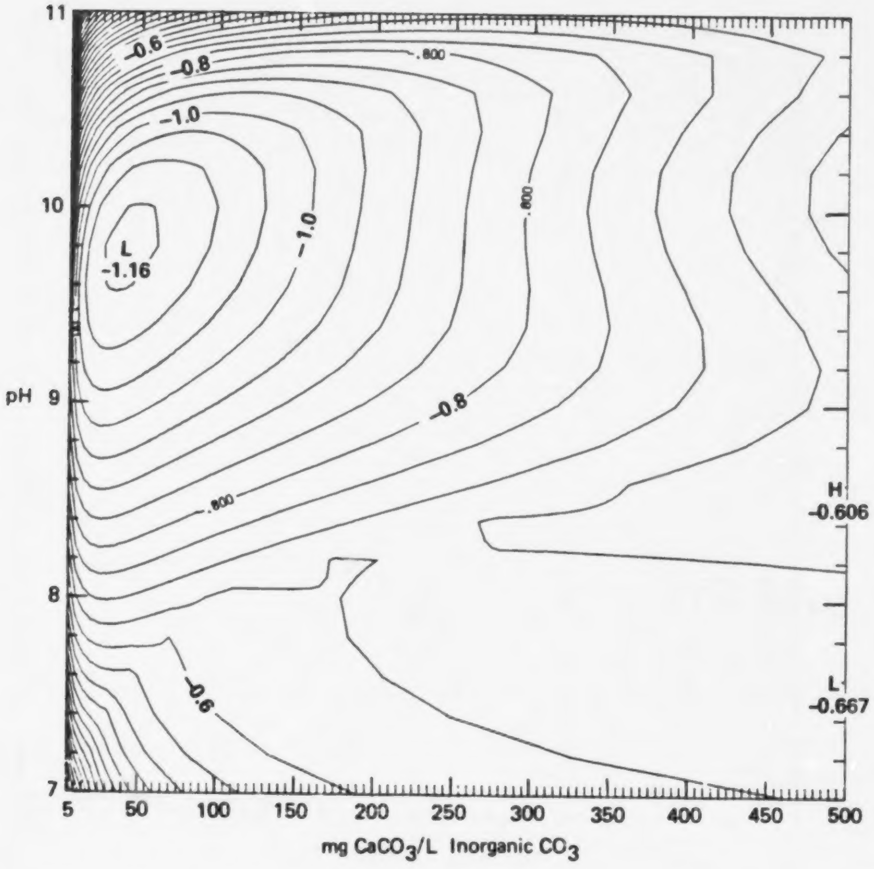

Figure 1. Contour diagram of lead (II) solubility in the system Lead (II)-Water-Carbonate at 25°C and an ionic strength of 0.005 mol/L. The MCL is -1.30 (0.05 mg Pb/L). The points marked "L" and "H" indicate local low and high points. The contour interval is 0.05 log units.

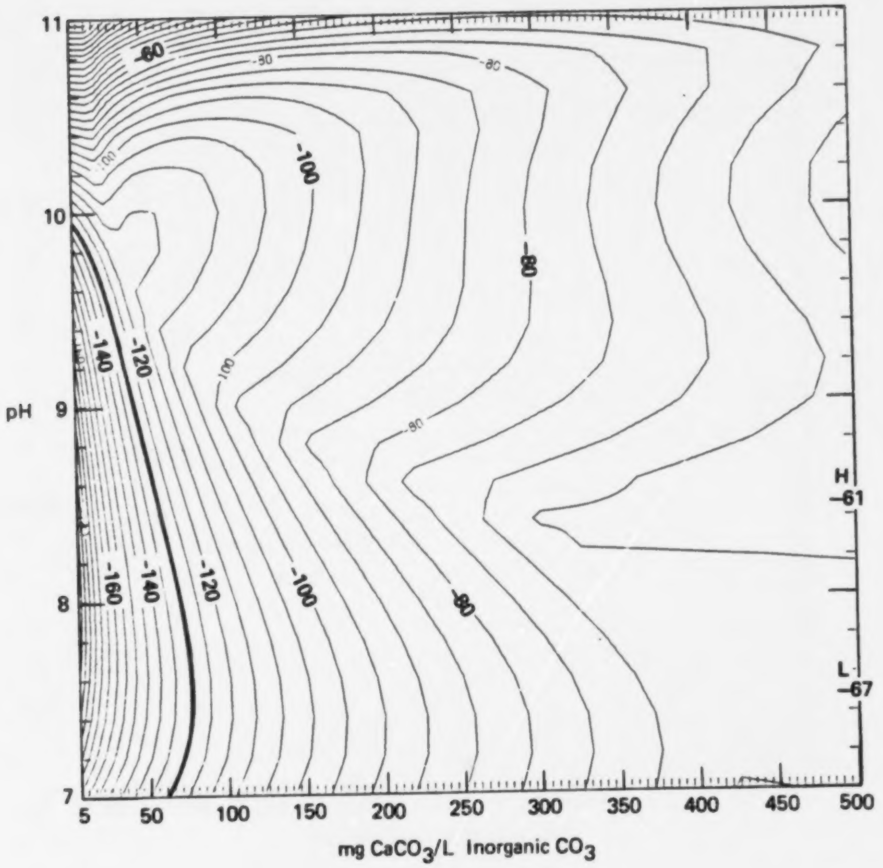

Figure 2. Contour diagram of lead solubility in the presence of 0.5 mg PO_4/L at I = 0.005 mol/L and 25°C. The MCL = -130 on this scale, which is: Log (mg Pb/L) x 100. The contour interval is 0.05 log units.

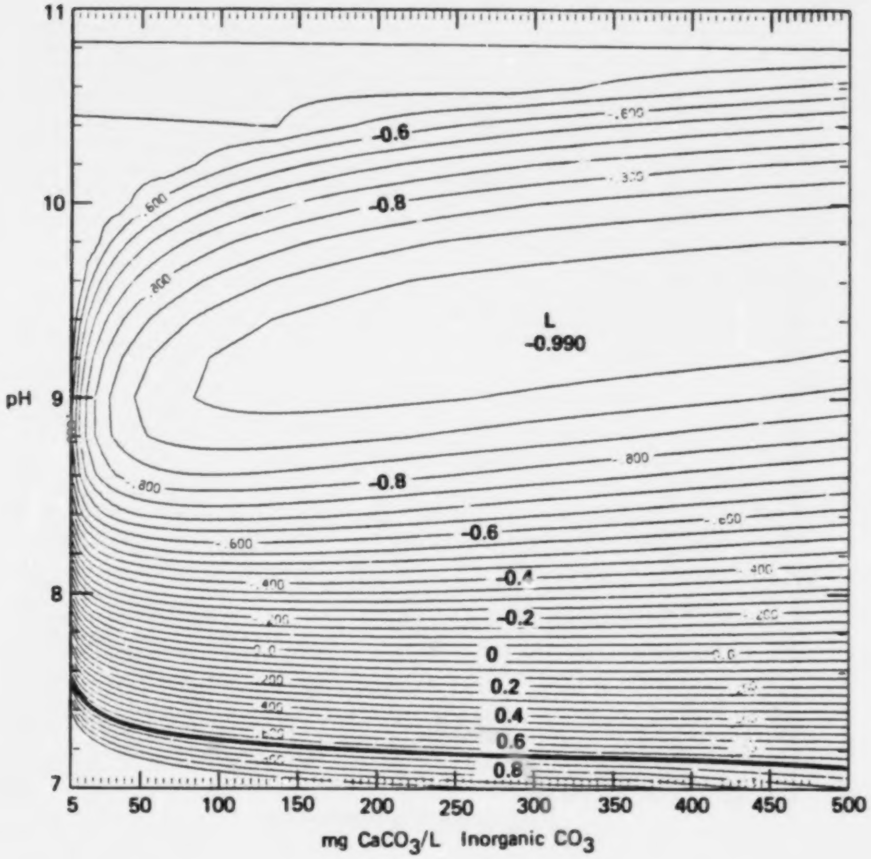

Figure 3. Contour diagram of zinc solubility in the system Zinc-Water-Carbonate at 25°C and I = 0.005 mol/L. The SMCL is 0.699 (5 mg Zn/L), and the contour interval is 0.05 log units.

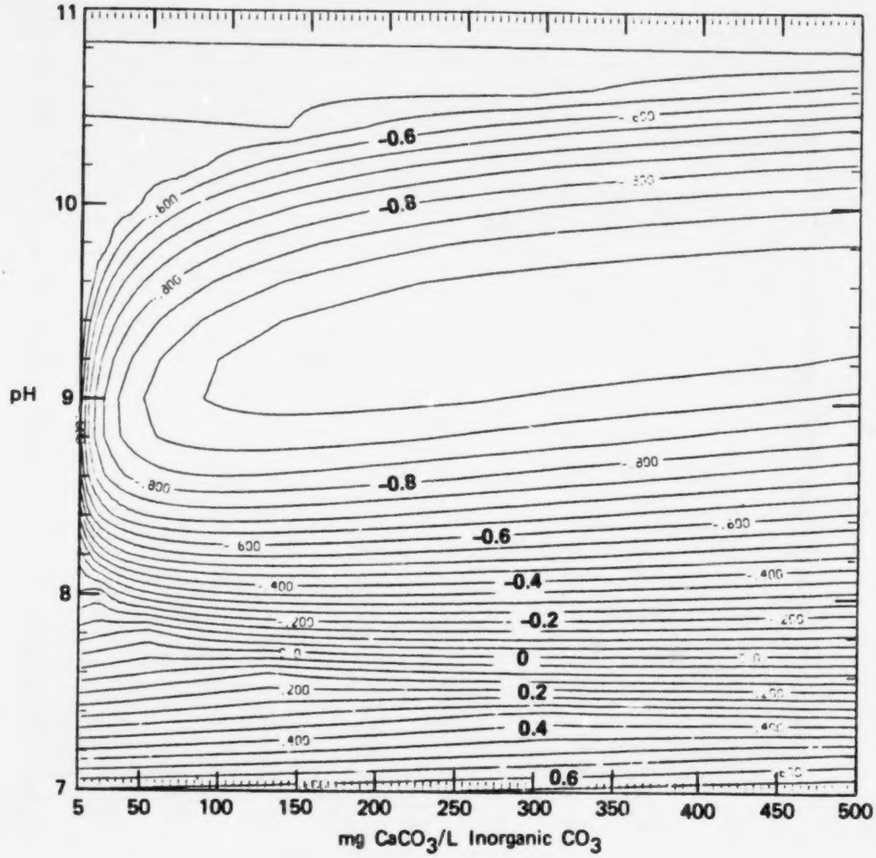

Figure 4. Contour diagram of zinc solubility in the presence of 0.5 mg PO_4/L at I = 0.005 mol/L and 25°C. All points lie below the 5-mg Zn/L SMCL (0.699 in diagram units). The contour interval is 0.05 log units. Lines were removed in the lower left to avoid crowding.

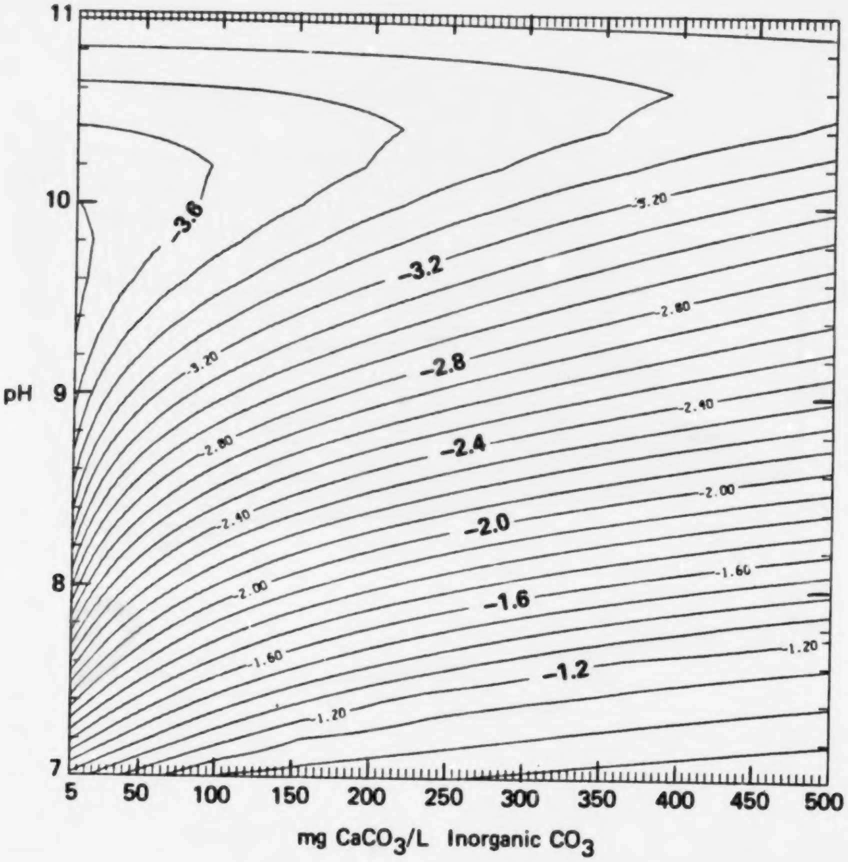

Figure 5. Contour diagram of copper (II) solubility in the system Copper (II)-Water-Carbonate at 25°C and I = 0.005 mol/L. All points lie below the SMCL of 1 mg/L (0.00 in diagram units). The contour interval is 0.1 log units.

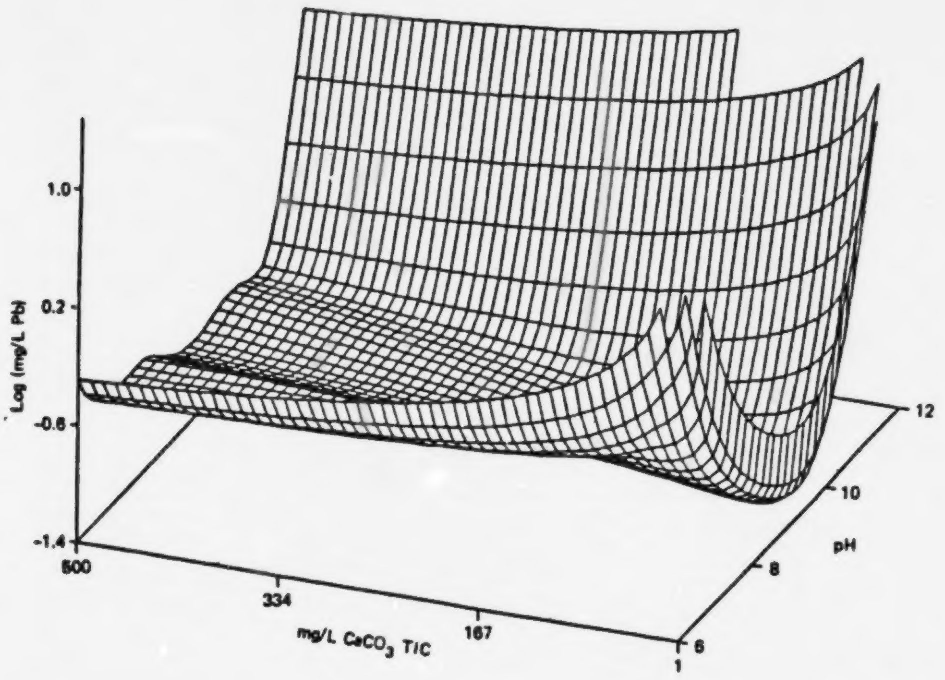

Figure 6. Three-dimensional solubility diagram for lead (II) corresponding to the conditions of Figure 1.

galvanized surface layer is of concern, because even at modest zinc solubilities the layer could be perforated if not "sealed" in time by the calcium carbonate coating.

In contrast to zinc and copper, lead (and soldered joints in copper pipe containing lead) could cause a serious problem (Figure 1). Assuming a pH range of 7.5 to 8.5 and a TIC concentration of approximately 200 to 400 mg $CaCO_3$/L (carbonate alkalinity of approximately 100 to 200 mg $CaCO_3$/L), the dissolved lead concentration could easily attain 0.16 to 0.25 mg/L upon overnight standing. Flowing samples could readily approach the MCL of 0.05 mg/L, given a sufficient length of pipe. Of additional concern is the fact that fresh leaded solder would generally be exposed immediately after house or building construction, or copper pipe repair. Leaded solder has also been noted for connections of plated brass household faucet assemblies (19). In some communities, lead is still either allowed or specified (20) for new service lines of small diameters (approximately 0.75 to 2 inches).

There are three special practical considerations in implementing a control program based on calcium carbonate saturation that should be noted. While the Langelier Index has been included as a parameter to be monitored in the EPA drinking water regulations (1), numerous researchers have pointed out that two waters of the same Langelier Index would not necessarily have the same potential mass of calcium carbonate to deposit (13, 18, 21). This value, the "calcium carbonate precipitation potential" (CCPP), is really the most enlightening index, and deserves to replace the Langelier Index as a control parameter.

The second consideration is that the identity of the calcium carbonate phase that precipitates is frequently the more soluble aragonite form, rather than calcite, the latter being the assumed phase in almost all calculations. Exactly what pipe, temperature, and water quality conditions govern this phenomenon have not been investigated to any great degree. To further complicate matters, a third form, vaterite, has been observed in some hot water systems (22). Log solubility constants vary from -7.91 for vaterite to -8.48 for calcite at 25°C and an ionic strength of zero. The solubility of each different form of $CaCO_3$ also varies in its response to temperature changes.

The third consideration is the fact that the most widely used values for the solubility constant of calcite at different temperatures have been shown to be in considerable error by studies over approximately the last decade (10, 23). Revised values based on the latest research have been presented (10, 23), and the widely used method of "total dissolved solids" correction originally developed in 1942 (24) has been revised (25).

PH ADJUSTMENT

Figures 1, 3, and 5 show that for a simple system consisting of the metal, water, and carbonate, the solubilities of lead (II), copper (II), and zinc can all be greatly reduced by increasing pH into the range of 9 to 10. In this pH range, in cold or room-temperature waters, the solubilities are controlled by hydrocerussite ($Pb_3(CO_3)_2(OH)_2$), tenorite (CuO), and probably hydrozincite ($Zn_5(CO_3)_2(OH)_6$). Lead is particularly sensitive to both pH and TIC, while pH is the dominant factor for copper (II) and zinc at TIC levels above approximately 20 mg $CaCO_3$/L.

While hydrocerussite and tenorite form tight and adherent scale layers, the films formed on zinc may not be as stable. Bachle et al. suggest that the corrosion products in the cover layer have no transport-inhibiting effect (26). Several studies have indicated conversions of an initially precipitated zinc oxide or hydroxide to a basic carbonate, and have indicated dehydration and phase changes in hot water systems (27-29). Changes in the morphology of the corrosion product of zinc with pH and TIC warrant continued investigation, in order to attempt to prevent removal of the thin galvanized layer, even while dissolved zinc remains below the SMCL level of 5 mg Zn/L. Essentially, no data is available for the dependence of complex formation and solubility constants of important lead (II), zinc, or copper (II) solids on temperature.

PH AND CARBONATE ADJUSTMENT

This treatment approach has been extremely successful in the case of lead, both in laboratory (8, 9) and field studies (30). Many waters contain sufficient carbonate to help limit lead (II) solubility, if only their pH is increased. A low alkalinity does not necessarily mean a low carbonate content, particularly when the pH is below 7. Because lead (II) forms strong carbonate complexes, only waters of very low carbonate concentrations are amenable to this treatment. Waters with high alkalinities and neutral to basic pH values may have to have carbonate removed to enable the attainment of the MCL.

Copper (II) also forms strong carbonate complexes, and its solubility is increased by carbonate supplementation in the pH range of pH 7 to 10.5. Copper (II) solubility remains below about 0.01 mg/L above pH 8.5, so maintenance of the SMCL should not often be a problem. Of considerable concern, however, is the possibility of rapid pitting (generally called "Type I" pitting) and perforation of the pipe wall. No consensus has been reached on the causes and mechanisms of pit propagation. Mattsson and Fredericksson (6) examined numerous corrosion products from systems with pitting, and concluded that in waters high in sulfate and chloride, basic copper (II) chloride and sulfate salts formed, rather than just tenorite and malachite. They suggested the ratio of bicarbonate to sulfate, or chloride, or both, could be important, but the effect might be pH-dependent. In this case, carbonate supplementation in addition to pH adjustment should prove to be beneficial.

Except for the pH range of 9 to 10.8 at high TIC concentrations, and the extremely low TIC region (10 mg $CaCO_3$/L) in the pH range of 8 to 10.5, zinc solubility is relatively insensitive to TIC. Thus, the benefit of carbonate supplementation might be analogous to the concept of calcium carbonate saturation control, wherein an additional mass of carbonate might tend to form a more effective film. There is no published experimental verification of this, however, and an improvement in corrosion resistance with continually increasing TIC should not be presumed. Here, there may be a difference in behavior as the underlying steel alloy layer becomes exposed, and the corrosion reactions of iron take over.

ORTHOPHOSPHATE ADDITION

In 1970, Murray (31) developed a corrosion inhibitor chemical from a mixture of zinc sulfate, monosodium orthophosphate, and sulfamic acid (31). He stated that the mechanism of corrosion inhibition was the formation of a protective coating of $Zn_3(PO_4)_2(s)$ because ". . . zinc phosphate is insoluble in water at all concentrations. . . ." That is obviously false, because zinc orthophosphate solid does have a measurable aqueous solubility constant (Table 3), but the chemical combination has become a useful corrosion inhibitor.

Lead (II) forms at least one orthophosphate solid of low solubility in realistic drinking water conditions, which can serve as the basis for corrosion control (9, 17, 30, 32, 33). Figure 2 shows that the predicted equilibrium lead (II) solubility can now fall below the MCL at low carbonate concentrations, with a dosage of only 0.5 mg PO_4/L. Experiments with both lead and galvanized pipes at U.S. EPA have demonstrated that supersaturation with zinc orthophosphate is not necessary for lead solubility control because the lead forms a passivating lead orthophosphate film (30). Investigations by the Water Research Centre in England (32) have indicated the solid to be hydroxypyromorphite, $Pb_3(PO_4)_2OH$. Successful field applications in England have been reported by Sheiham and Jackson (32).

The passivating action of the orthophosphate depends on the pH, the TIC concentration, the orthophosphate concentration, and temperature. No data is available on the effect of the latter. On new lead surfaces, a very thin, smooth film is formed. Taylor (34) has suggested that the orthophosphate might not be as effective if the pipe surface is already covered with corrosion products and deposits (34).

If the solubility constant for $Cu_3(PO_4)_2 \cdot 2H_2O$ is accurate, and if it is a realistic phase that would precipitate in drinking water systems, then orthophosphate addition would be of little benefit for copper level control. Solubility calculations were performed for orthophosphate levels up to 2 mg PO_4/L, and no precipitation of a copper (II) orthophosphate solid was predicted. If either or both of the solubility constants used for tenorite and malachite are too low, then this conclusion would have to be reevaluated. A zinc orthophosphate coating on the copper could only be deposited if its solubility product would be exceeded. High concentrations of zinc and orthophosphate might be required, depending upon the pH.

Figure 4 shows the solubility diagram for zinc when a dosage of 0.5 mg PO_4/L is added, and $Zn_3(PO_4)_2 \cdot 4H_2O$ (-hopeite) is the probable solid orthophosphate precipitate. At pH values under 7.5 and at low TIC concentrations, some solubility suppression is likely. Increasing the orthophosphate concentration would extend the stability domain of -hopeite. Zinc leaching from galvanized pipe might be slowed or limited by the mass-action principle, if zinc ion were added to the water along with the orthophosphate inhibitor. More research in this area is definitely needed.

Four advantages to orthophosphate addition plus pH adjustment are apparent. First, for at least lead and zinc, the same solubility can be attained at a lower pH than using pH plus carbonate alone. This assists disinfection and slows organic halogen formation in chlorinated supplies. Second, orthophosphate may be beneficial to the iron-zinc alloy substrate beneath the galvanized layer, yielding superior protection where the surface layer is finally penetrated. This area needs significant investigation. Third, the same treatment strategy might also benefit asbestos cement, cast iron, or cement mortar-lined distribution pipe lines. A fourth advantage is that for waters with high carbonate contents, a significant reduction in lead solubility would be possible without softening or decarbonation.

POLYPHOSPHATE ADDITION

Polyphosphates are strong chelating agents for calcium, magnesium, iron, and other trace metals. While they have useful properties for reducing scaling, cleaning tuberculation from distribution mains, and reducing "red water" complaints through sequestration of Fe^{2+} ion, they have not been proven useful in reducing the solubility of zinc, copper, or lead. Even though they may be somewhat effective relative to nontreatment, particularly in acidic waters, alternative treatment strategies will virtually always prove superior in reducing metal levels. Any joint use of polyphosphate chemicals with another treatment (such as to prevent scaling at high pH, or with sodium silicate) must be accompanied by thorough monitoring of trace metal concentrations. This is necessary because the actual polyphosphate ligands have not been identified, and their complex formation constants have not been determined, making even semiquantitative estimates of effect through solution modeling calculations very unreliable.

SILICATE ADDITION

Silicate addition has been demonstrated to be an effective procedure for corrosion inhibition of galvanized steel pipes, particularly at high temperatures. Studies by Glasser and Lachowski of the structures of silicate solutions (35) concluded that there is essentially no difference between those prepared by the dissolution of anhydrous sodium metasilicate or by salts with sodium orthosilicate groups. Therefore, either type of additive should provide similar results for corrosion inhibition.

Early studies with galvanized and brass drinking water pipes indicated that the silicate additive (8 to 12 mg SiO_2/L) helped form amorphous films binding corrosion products of the metal, and additionally enmeshing iron oxide and organic particles present in the water supply (36). Thus, an initial corrosion product needed to be present in order for the silicate to work effectively. Similar conclusions may be drawn about the silicate action on limiting the dissolution of zinc electrodes, zinc oxide, and zinc dust through the formation of adsorption compounds that control zinc ion diffusion (37). Silicate treatment may, therefore, bridge the gap between control of zinc levels in solution by the precipitation of basic zinc carbonate, zinc hydroxide, or zinc oxide, and sustaining the life of the zinc coating by the formation of a uniform and adherent passivating film.

An indication of this potential has been given by studies done at the Illinois State Water Survey with simulated domestic hot water systems (38, 39). In waters of low carbonate content, a film of zinc pyrosilicate was apparently formed at a pH of 8 and a dosage of 8 mg SiO_2/L at 60°C (140°F). However, in waters with higher carbonate contents, an adherent scale of basic zinc carbonate mixed with silicate was found (38). Further experiments were conducted to better define the optimum pH and silicate dosage in a water of approximately 100 mg $CaCO_3$/L total hardness, 35 to 55 mg $CaCO_3$/L total alkalinity, and 8 mg SiO_2/L natural silicate (39). An initial high dosage of silicate (28 mg SiO_2/L total) was found to be useful to provide more immediate corrosion inhibition and less bulky scale formation, but the optimum dosage for this water quality was about 18 mg SiO_2/L at a pH of approximately 8.5. Corrosion inhibition in these experiments was monitored by the use of standardized ASTM pipe coupon inserts for weight-loss determinations (40). Silicate requirements tended to be less as the pH was increased by caustic soda additions. The authors concluded that in the hot water systems, the optimum silica concentration and pH may be different for waters of higher alkalinity, where more basic zinc carbonate corrosion product would be formed, whereas primarily hemimorphite ($Zn_4Si_2O_7(OH)_2 \cdot H_2O$) was found in this study. Little or no calcium carbonate deposition was detected. They also indicated that other water quality factors, such as chloride, sulfate, calcium, and magnesium, could change the dosage requirements and could influence properties of the scale.

In a study of two fairly soft waters in Seattle, sodium silicate addition at a pH of 8.0 considerably reduced the corrosion rates of black steel pipes compared with other treatments investigated (41). After two or three months of exposure of galvanized steel pipe coupons, the silicate treatment showed slightly inferior results to that attained by lime plus soda ash. Obviously, the interplay of pH, silicate dosage, and initial corrosion product formed on the pipe is of critical importance at low temperatures as well as in hot water systems. Further investigation is necessary before treatment guidelines can be given with much confidence.

Silicate addition has not been found to be particularly effective for copper pipe, although few studies have actually been conducted. No apparent reaction was found (38) between copper metal and a soft water containing 8 mg SiO_2/L at pH 8.4 at 60°C (140°F). The "control" experiment in this study was at pH 6.7, making a direct comparison of the effect of pH adjustment alone to the different inhibitors tested very difficult. Also, in waters tested having a high hardness, calcium carbonate precipitation was suspected, making resolution of the role of the sodium silicate inhibitor difficult. The scales seemed to offer good corrosion resistance, however.

In the Seattle study (41), silicate addition proved to be advantageous only in keeping even the initial corrosion rates of the copper specimens low. After three months of exposure, alternate treatments such as lime plus soda ash or lime plus zinc orthophosphate were equivalent or superior.

Some experimental tests have been conducted with lead pipe (30, 32), and observations of the inhibitory effect of naturally occurring silica have been summarized (30). After approximately 8 to 9 months of exposure to 20 mg SiO_2/L, lead levels were slowly reduced in a soft, low-alkalinity water at pH 8.2. In systems with both new galvanized and lead pipes and 10 mg SiO_2/L concentration, lower lead levels were observed with continued exposure. These levels were at approximately the 0.05-mg Pb/L MCL, but presumably the pH and TIC content of the water would be important variables to consider before extrapolating results. These experiments tend to support the idea of the slow formation of a film on new pipe, but which might become effective over the long term as a "cementing" agent for other corrosion products. Corrosion films on lead pipe always tend to be very thin and uniform, unlike those on galvanized pipe. Sheiham and Jackson (32) conducted some experiments with low alkalinity moorland waters and concluded that 10 mg SiO_2/L had little effect on lead dissolution.

CONCLUSIONS

Case studies and solubility calculations for zinc, copper (II), and lead (II) in drinking water show that several control strategies have been proven to be adequate for the attainment of current MCLs and SMCLs. The most difficult metal to control is lead, and for some water chemistries flushing of the lines before taking water for human consumption may be required if optimization of treatment for lead corrosion control cannot be accomplished. Lowering of the lead MCL to 0.025 or 0.01 mg/L would cause considerable difficulty in light of current knowledge about available inhibitors.

In order to develop efficient and accurate treatment techniques, considerable effort must be expended in the future to understand the mode of action of phosphate and silicate inhibitors, as well as the chemistry of lead, copper, and zinc in response to changes of pH, TIC, and temperature. This research is vital both to ensure the toxicological purity of the water, and to extend the life of plumbing materials of diverse composition in the same water distribution system.

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DRINKING WATER REGULATIONS AND THEIR IMPACT ON MATERIALS USED IN WATER SYSTEMS

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Regulations and plumbing code requirements have a very definite influence on the materials used in water systems and house plumbing. Such regulations are necessary to provide for protection of the public health where the combination of water quality and piping materials may result in hazardous conditions. One of the problems of greatest current concern is the presence of heavy metals in drinking water resulting from lead or other piping materials being used to convey waters that are highly corrosive.

A number of regulations have been developed at both federal and state levels in an attempt to prevent health hazards. The U.S. Environmental Protection Agency (EPA) is currently in the process of adopting national revised primary drinking water regulations (1). The current interim regulations specify maximum contaminant levels for microbiological, inorganic, and organic chemicals and radionuclides (2). The maximum contaminant level (MCL) means "the maximum permissible level of a contaminant in water which is delivered to the free flowing outlet of the ultimate user of a public water system." These MCLs are currently being reviewed and in a number of instances may be significantly lowered.

In addition to the MCLs, the interim regulations also include requirements to identify the presence of specific materials in distribution systems and to monitor for corrosivity. This requirement stems from increasing concern about corrosion byproducts and particularly the much higher levels of metals observed in corrosive water when that water stands for some time in house plumbing systems. The interim regulations require that all community water systems sample their water twice during a one-year period and report the Langelier index as an indication of the corrosivity of the water. This testing is required in order to enable the primary enforcement agency to determine which water supply systems should initiate corrosion control measures. The approach being considered for the revised primary drinking water regulations is to set specific monitoring requirements for corrosion byproducts such as lead and cadmium. The systems known to have corrosive water will be required to take sufficient samples to insure that MCLs for the corrosion byproducts will not be exceeded. Under this interim regulation the states were encouraged to implement corrosion control measures at systems distributing corrosive waters. Much has been written about the shortcomings of the Langelier index as a measure of corrosivity but, since no better test has been developed, this remains the index of choice.

EPA has also developed Water Supply Guidance Number 73 on sampling techniques to be used for compliance monitoring for metals in drinking water (3). These sampling techniques are not federally enforceable but are intended to provide a standardized method for testing for corrosion byproducts. This guidance provides for collection of three samples: from a house faucet to represent the water that has been standing overnight in the house plumbing, from the service line to the house, and from the distribution system. Rather than using this sampling protocol to determine MCL violations, it is to be used more as an indication of the potential for exposure to higher levels of corrosion byproducts than would be identified from the usual primary inorganics testing.

In addition to federal and state drinking water regulations, plumbing code requirements also influence materials used in house plumbing systems. The plumbing codes of most states are based upon some national model such as the Uniform Plumbing Code. The Oregon Code with which I am familiar is based upon the Uniform Plumbing Code of the International Association of Plumbing and Mechanical Officials with local variations to meet Oregon requirements (4). One interesting feature of the Oregon Plumbing Code is a provision that the Administrator of the Health Division may prohibit the use of any pipe, solder, fillers, or brazing materials which do not conform to product acceptability criteria adopted by the Health Division. The Oregon Code specifies that the approved materials used in house plumbing may include brass, copper, cast iron, galvanized malleable iron, galvanized wrought iron, galvanized steel, polybutylene (PB), chlorinated polyvinyl chloride (CPVC), or other approved material. Polyethylene (PE) and polyvinyl chloride (PVC) water pipe may be used only for cold water systems outside of buildings. Lead pipe is not permitted in potable water systems.

Oregon law was changed in 1979 to give the Health Division more direct influence over plumbing regulations. This was due in part to problems in the 1970s with galvanized pipe imported from overseas that was not manufactured to American standards and resulted in serious taste and odor problems, rapid corrosion, and some potential for gastrointestinal upset. The State Legislature amended the law relating to regulation of plumbing to require that all potable water pipe sold in Oregon be clearly marked with the identification of the manufacturer and plant of origin. This permits easier tracking of inferior pipe.

Recent regulatory changes throughout the country have taken a number of directions. This may be due in part to a lack of federal standards for corrosion testing and MCLs for corrosion byproducts. A number of cities have become concerned about the potential health effects of corrosion and corrosion byproducts and have funded engineering and medical studies to evaluate the impact of corrosion. The problem with lead in drinking water is certainly not new in this country. In an 1845 report to the City of Boston (5), it was concluded that: "Considering the deadly nature of lead poison, and the fact that so many natural waters dissolve this metal, it is certainly the cause of safety to avoid, as far as possible, the use of lead pipe for carrying water which is to be used for drinking." The advice was not heeded, however. In 1920 another Boston report (6) stated: "If water supplying such works be found to attack lead, the best plan is to replace them gradually, meanwhile protecting consumers by proper treatment of the water supplied through existing services." Boston's approach to resolving the problem was to provide treatment to reduce the corrosivity of water. Tests run on water from consumers' taps in Boston before and after implementation of treatment showed a significant drop in lead concentration from above 0.05 mg/L to consistently below that level. This is accomplished by pH adjustment to approximately 8.5 using sodium hydroxide. Much lead pipe plumbing remains in use in the Boston system.

In other parts of the country, notably Seattle and Portland, some lead service connections remain, but a significant source of lead appears to be from lead-based solders used to join copper pipe and fittings.

The State of Delaware is the only state to date that has elected to ban the use of lead-based solder for potable water systems. The Delaware plumbing code requires that soldered joints in copper tubing and fittings shall be made with solder conforming to ASTM B32, provided that the lead content shall not exceed 0.20 percent for potable water systems. This in effect will require that tin-antimony or tin-silver solders be substituted for the usual 50/50 tin-lead solder.

The City of Seattle has used two soft surface-water sources for many years. Complaints about rusty water or blue stains and resulting taste problems led the City of Seattle to sponsor an extensive engineering study of corrosion and corrosion effects in the Seattle water system (7). The study confirmed that both sources of water were corrosive and exposed the Seattle customers to corrosion byproducts such as lead in addition to the esthetic effects. Seattle's approach to the problem was two pronged — the adoption of a number of amendments to the Uniform Plumbing Code and the provision for treatment of water to neutralize corrosivity. Amendments to the Plumbing Code included the banning of lead solder, the requirement for an approved dielectric fitting when connecting piping of dissimilar materials, and the approval to use PB or CPVC as hot or cold water piping in buildings not exceeding four stories in height. In addition the City now prohibits the use of house plumbing systems for electrical ground.

The treatment applied in Seattle consists of the addition of lime and sodium bicarbonate to increase the pH and alkalinity of both sources. Incidentally, Seattle's engineers estimated that there would be a net annual savings to the consumer, looking at a benefit/cost ratio of 5.4:1 when comparing the total annual cost of the treatment versus the projected net annual consumer plumbing maintenance cost savings.

Portland also had an engineering study performed which confirmed that the untreated water from Bull Run River is also highly aggressive (8). Although the Portland system still contains roughly 10 percent lead services or pigtails, the engineers felt the major health risk was from lead solder in newer copper-plumbed systems. A supplemental study was done on some non-copper-plumbed houses that were known to have lead pigtails, and it was concluded that the lead spike that occurred in water standing within the pigtails would be dispersed below MCL levels before reaching the kitchen tap. It was concluded then that Portland should continue to replace lead pigtails as they were found and that banning lead solder in new copper plumbing would be sufficient to protect the public health.

Portland's first approach to the problem was to consider banning lead solder by ordinance in the City of Portland, but later requested that the State Health Division ban lead solder statewide since Portland serves water to a number of water districts outside the city limits. A city ordinance would have no effect within these districts. The Health Division was concerned that, although banning lead solder would solve a major part of the problem with new construction, there would still be concern about the health risk exposure from existing plumbing systems. The state held a number of informational hearings to receive comments on a proposed lead solder ban and other options. Much comment from the plumbing industry centered on the difficulty of using the alternative solders due to their narrower working temperature range and the consequences of greater expense for new construction. Many comments reflected a concern that such a proposal would be unenforceable and was not necessary in many areas of the state where hard groundwater sources are used. Some testimony was received from communities that already provided full treatment, including pH correction, that the lead solder ban was unnecessary.

The State of Oregon is still considering a number of alternatives, including a statewide ban on lead solder with certain regions of the state eligible for an exemption from the ban, and a monitoring program to improve identification of communities that have corrosive water followed by a requirement that those communities prepare plans for corrosion control. Oregon will shortly draft a proposed rule incorporating the alternatives and will schedule a series of formal hearings to receive testimony prior to adoption or modification of the rule.

It is obvious that regulations and plumbing code requirements take a number of directions as concerned officials search for methods to safeguard against potential health risks. There are two major difficulties with the problem of corrosion byproducts. First, in the case of lead and perhaps other heavy metals, the effects are accumulative and chronic exposure to low levels may result in health impacts that are difficult or impossible to measure. Studies done by Dr. Needleman of the Harvard Medical School (9) confirm that children exposed to low lead dose levels performed less well than children not so exposed, even though neither group showed any other symptoms of lead poisoning. A second difficulty with the problem of lead in water is the lack of adequate methods for measuring corrosivity.

Under these circumstances regulatory officials have an obligation to take a conservative approach and require all reasonable methods to minimize or to prevent any uptake of lead through drinking water. Since there are reasonable treatment or control methods available, communities should voluntarily be providing corrosion control. Such treatment also will have esthetic benefits that will more than offset treatment or control costs.

Although there has been a great amount of research done on corrosion, the water supply industry still has no simple reliable test to measure it. Coupon testing has been suggested as an accurate measurement of corrosion, but time required for the testing makes this impractical. I would challenge the research community to develop a standard method for measuring corrosivity by exposing a volume of water to a specimen of lead, leaving the water standing for a selected time, then measuring the lead uptake in the water. It appears a reproducible laboratory test could be developed that would approximate water standing in a plumbing system. This type of test is urgently needed to help provide answers to questions being raised by a concerned public.

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EUROPEAN DEVELOPMENTS IN USE OF PLUMBING MATERIALS

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INTRODUCTION

The plumbing materials used in Europe during the last century were lead, copper, and galvanized steel. Recently plastic materials, especially cross-linked polyethylene, came on the market for residential drinking-water installations. Depending on the distribution method, individual countries made greater or lesser use of different plumbing developments.

Changes in the quality and use of plumbing materials were due to changes in price or technical quality (mainly due to corrosion), and health considerations. With these changes, use of lead plumbing in Europe decreased nearly to nothing, and the installation of cross-linked polyethylene pipes in a double-tube system with metallic joints became commonplace.

Although the cost of plumbing systems in new-house installations, mainly in Germany, increased over the last 30 years (with the ratio of galvanized steel to copper pipes changing from 6:1 to 3:2), the use of lead was ruled out because of health problems. Polyethylene pipe was developed mainly to correct local corrosion problems caused by metallic pipe. More detailed information on the different materials, their quality standards, and their characteristics are given below.

LEAD

Lead plumbing and lead distribution systems were used in Europe to a great extent when central water-distribution systems were being developed, in the later decades of the 19th century. In spite of warnings to be found in the literature since the end of the 18th century, lead was the preferred plumbing material up until the late 1930s.

The regulations covering lead varied by country. For example, to reduce lead uptake by water, Prussia recommended that lead had to be free from other metals. The Netherlands passed a regulation requiring a layer of tin inside lead pipes and, when that was discovered to be hazardous, amended the regulation to require the tin content to be 99.5 percent.

In other countries, mainly in some German states, lead was banned completely, beginning with Wuerttemberg in 1878 (1). Lead was finally ruled out in Germany in 1972 with the introduction of the new German Standard DIN 2000. (A general survey of this development is given in Table 1.)

Similar developments took place throughout Europe at a pace dependent on the national regulations and possibilities. In the United Kingdom, for example, a recommendation against the use of new lead pipes was given in the early 1970s. The last new lead plumbing systems were installed in 1976. Table 2 shows the development of recommendations in Great Britain.

These very restrictive measures concerning lead plumbing were supported, mainly with respect to the old distribution systems, by a lot of research into water quality and levels of lead in drinking water. Numerous studies and surveys have been performed and published in the last 10 years (3,4,5). The main conclusion reached was that the level of lead in both soft and hard waters nearly everywhere exceeded the Maximum Acceptable Concentration (MAC) values, often to a high extent. The solution to this problem was either replacement of lead by other materials or treatment of water to reduce lead solubility (6).

The questions to be answered in this case were addressed by studies performed in the United States (7) and the United Kingdom (8) on the stability or solubility of lead compounds. Additional data were gathered (9) by monitoring and calculating lead levels as a function of standing time; the maximum solubility of lead in water was reached after long standing time.

With respect to the arguments of European toxicologists (10, 11) that even low lead concentrations have to be seen as a cumulative poison, the longtime uptake should be evaluated. With this goal, further research was performed on consumption patterns of households in the United Kingdom and Germany (12, 13). Lead levels were compared depending on maximum concentration, kind of pipe, pipe length and diameter, flow velocity, and standing time. These data allow for the calculation of general and individual lead intake by a minimum of monitoring and analysis.

COPPER

The use of copper pipes was generally unrestricted due to health considerations. Nevertheless, blue or green discoloration of water due to stagnation (standing time) — mainly in acid waters — demonstrates that copper pipe can cause heavy metal uptake in water after a long stagnation

TABLE 1

LEAD: STANDARDS AND RECOMMENDATIONS IN FEDERAL REPUBLIC OF GERMANY

YEAR(S)	REGULATION
1878-1972	Ban on lead pipes for distribution and house installation in different German states, beginning with Wuerttemberg (1878)
1972-present	Total ban for new installations in lead (DIN 2000)
1980/81-present	Study on Drinking Water and Lead (DVGW-Research Institute, Karlsruhe) Results: ● Connecting pipes to be replaced depending on pipe length and water quality. ● In house installations, MAC (40 ppb) is regularly exceeded. ● Flushing and orthophosphate dosage may be used as immediate measure. ● House installations in lead must be replaced as quickly as possible.

TABLE 2

LEAD: RECOMMENDATIONS AND MEASURES IN GREAT BRITAIN

YEAR(S)	REGULATION
1976-present	Lead plumbing not further in use for new plumbing systems
1976-78	Countrywide survey on "Lead in Drinking Water" (DoE)
from 1980	Drinking water treatment: ● by pH increase in soft water ● by o-phosphate dosage in hard water
from 1982	Survey on consumption patterns in households (WRC)
	General exception in Great Britain: No pressurized systems in house installations; roof tanks, only kitchen tap under pressure

time. Water treatment by pH adjustment was therefore recommended in order to reach drinking-water standards. As a result of corrosion problems, the development of German Standards on copper pipe qualities was recommended.

Contrary to British and North European recommendations, the German experience with copper pipe allowed for a certain level of carbon or lubricant in the pipes. Since copper was used normally only in soft waters or in hot-water installations, this allowance worked well. However, with an increasing amount of copper-plumbed cold-water systems in regions with hard groundwater, Type I pitting began to occur more frequently and finally accounted for more than 70 percent of all corrosion cases (14). The standards on lubricant, mainly carbon, on the inner pipe surfaces were changed and the permissible levels decreased sharply. As a consequence of that change, more hot (hard) soldering took place; after a while, pitting in cold-water pipes increased once again. Thus the permissible carbon and lubricant concentrations have been reduced again and a new surface treatment on soft copper pipes has been introduced. These new pipes, which have been in use for about 3 years, seem to meet the necessary specifications; only a few cases of copper pipe failures have been reported.

The development of the German Standards governing copper pipe is given in Table 3.

Although the use of copper pipe has presented no health problems, the use of copper pipe in house installations is a concern due to the soft soldering used to join the pipe. Most solders were tin/lead or tin/antimony alloys or mixtures with differing lead content.

In the previously cited survey (2) on lead in the U.K., nearly 3,000 houses were monitored; with a certain astonishment, analysts registered concentrations of lead in standing waters of copper-plumbed systems that were higher than in lead-plumbed systems. Detailed research at the Water Research Centre (15) in the U.K. and at KIWA (16) in the Netherlands has shown that soft solders with lead content allow a high quantity of that lead to migrate.

Similar research in Germany (17) studied the migration of lead out of soft solders and of cadmium out of hard solders. The results were not considered to be a problem of heavy metal uptake by water but, interpreting the data correctly, it must be accepted that under actual pH conditions, lead and cadmium uptake could become a severe health problem like that found in U.K. and the Netherlands.

However, standards on solders have changed now in the U.K., the Netherlands, and Germany. Soft solders now have to be free of lead; this requirement is most important to the British plumbing systems, which were normally installed with soft solder. The development of standards in Europe is illustrated by the change in German Standards for soft and hard solders. Table 4 shows the changes in the allowed solders, comparing the standards for 1972 and 1983. Note that the change to solders that are free of cadmium, antimony, and lead is complete.

TABLE 3

DEVELOPMENT OF STANDARDS FOR COPPER PIPE IN DRINKING WATER INSTALLATIONS[1]

1972	1981	1983
Cu-hard Lubricant (10 mg/dm^2)	Cu-hard Lubricant (4 mg/dm^2)	Cu-hard Lubricant 1 mg/dm^2 (diam. 2") 2 mg/dm^2 (diam. 2")
Cu-soft Carbon 2 mg/dm^2	Cu-soft Carbon 0.8 mg/dm^2	Cu-soft Carbon 0.2 mg/dm^2 (no carbon films allowed)

[1] Derived from DVGW-Arbeitsblatt GW 392, Standard of German Gas and Water Association.

TABLE 4

DEVELOPMENT OF STANDARDS FOR SOLDERS ON COPPER PIPES IN GAS AND DRINKING WATER INSTALLATIONS[1]

SOLDER	1972	1983
Hard solders	Ag 40 Cd Ag 30 Cd Ag 2 P	Ag 34 Sn Ag 44 Ag 45 Sn Ag 2 P Cu 6 P
Soft solders	Sn Ag 5 Sn Sb 5 Sn 50 Pb	Sn Ag 5 Sn Cu 3

[1] Derived from DVGW-Arbeitsblatt GW 2, Standard of German Gas and Water Association.

TABLE 5

GERMAN STANDARD FOR MILD STEEL PIPES TO BE GALVANIZED[1]

1961	1972	1978
Clean and complete welding seam	Surface must be free from scales and shells Welding seam has to be cut; maximum height is limited to 0.3 d + 0.05 d (d = thickness of pipe wall)	Mechanical tests included bending stress

[1] Derived from Standard DIN 2440.

GALVANIZED STEEL

Galvanized steel as a plumbing material is used hardly at all in the U.K. and only to a small extent in northern Europe. In contrast, central European countries commonly use galvanized steel as a plumbing material, to the extent that it accounts for 60-80 percent of all piping material.

When standards for galvanized steel were set, especially in Germany, the primary concern was to avoid corrosion due to deterioration of the material. Standards therefore had to meet noncorrosion requirements. The German Standard developed as shown in Table 5 above; the 1961 standard for the steel pipes was upgraded in 1972 to recommend cutting the welding seam, and in 1978 mechanical strength tests on the welded pipes were added to the standard. Experience had shown that the welded seams in galvanized steel pipes were the primary source of material failure due to pitting (18).

An additional standard governed the quality of the zinc layer in the galvanized steel pipes. Again, protection against corrosion (of the zinc layer) was the primary concern: "Zinkgeriesel," a type of selective corrosion of the zinc layer, leads to the presence of sandy, zinc corrosion products in house installations, often combined with heavy red water problems. Research over a period of 15 years proved that most of these problems were caused by the bad quality of the zinc layer of airblown pipes (19).

Table 6 shows the continuing development of the standard governing galvanized steel pipes. The health aspect was addressed in 1972 by reducing the cadmium level in zinc to a maximum of 0.1 percent and fixing the lead content of the zinc layer at a maximum of 1 percent. Additional recommendations on the quality of the zinc layer were introduced, and steam-blown pipes with smooth, tight zinc surfaces became standard. The most recent (1978) change to the standard occurred after research on the cadmium and lead uptake of water by corrosion of the zinc layer showed that cadmium and lead levels often were higher than drinking-water standards allowed (20), even after standing times of only a few hours. The amount of cadmium allowed in the zinc layer was therefore reduced to a maximum of 0.01 percent. The lead content of the layer, made necessary by the galvanizing process (the galvanizing tub requires a lead surface to avoid crystallization of metallic zinc), was reduced to a maximum of 0.8 percent. Lower concentrations should be reached. Data show that the mean level of 0.5 percent lead in the zinc layer of galvanized steel is not generally reached.

PLASTIC MATERIALS

The installation of plumbing systems made completely of plastic piping is only now becoming common in Europe. Many such installations have been temporary, made by introducing cross-linked polyethylene as a plumbing material. Previous attempts, mainly with polyvinyl chloride (PVC) piping

TABLE 6

GERMAN STANDARD FOR GALVANIZING MILD STEEL PIPES[1]

1963	1972	1978
Zinc must be a minimum of 98.5% pure	Cadmium content in zinc limited to 0.1%	Zinc to be used must be free of cadmium
Coating must cover whole surface and be free from local accumulations of zinc	Lead content is limited in zinc layer to 1.0%	Cd content of the zinc is maximum of 0.01% Lead content is limited to the technological necessity: less than or equal to 0.8% Pb
Coating must have minimum quantity of 400 g/m^2	Inside surface must be free of impurities and produced by steam blowing	Production must be supervised by independent material testing institute. Pipes must be signed by durable continuous printing.

[1] Derived from Standard DIN 2444.

in cold-water installations, aroused no interest except in industrial or technical water supplies where special corrosive waters (e.g., fully softened or desalinated) are distributed and most plumbing is placed on the wall.

Nevertheless, numerous nonmetallic materials are used in drinking-water distribution and plumbing installations. In addition to the hard-PVC pipes and polyethylene pipes in distribution networks, many coatings of reservoirs, fittings and armatures, gaskets, and other products in contact with drinking-water plumbing systems are made from plastics (or, more generally, nonmetallic materials).

Recommendations were developed in different European countries in order to guarantee that the quality of nonmetallic materials would have no undesirable health effects. Initial recommendations and test methods covering materials in contact with drinking water were developed (in the Netherlands and the Federal Republic of Germany) to regulate specifically the leaching of lead from lead-stabilized, hard-PVC tubes in contact with drinking water.

Later recommendations covered other questions, for example organoleptics, migration of total organic carbon (TOC), chlorine and oxygen demand, and microbiological aspects. The emphasis differs from country to country; while in Great Britain the recommendations are based mainly on microbiological aspects (21), in Germany the recommendations and methods have a more chemical and analytical direction (22).

Table 7 shows the general points of view of the German regulations (the KTW regulations). In addition to the general points covered in Table 7, the parameters vary depending not on the specific material but on the range of use. This regulation was based on the premise that the surface-area/volume ratio and the contact time negatively influence water quality. Table 8 gives the limits of the basic requirements depending on the range of use. If special requirements concerning specific compounds are found to be necessary depending on the particular use, these additional parameters will be limited with respect to the range of use of the product.

Microbiological tests are likely to be added to KTW recommendations; currently only a DVGW-Arbeitsblatt (23) covers this matter especially to describe requirements on lining materials of drinking-water reservoirs.

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TABLE 7

KTW EMPFEHLUNGEN (RECOMMENDATIONS) FOR PLASTIC AND OTHER NONMETALLIC MATERIALS TO BE USED IN DRINKING WATER DISTRIBUTION SYSTEMS[1]

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1. Material compounds (recipe) must be in accordance with positive lists, including limited amounts of compounds (each compound to be approved by toxicological working group)

2. General limits:

   - on taste and odor, color, turbidity and test water.
   - on migration of total organic carbon in test water.
   - on chlorine demand in chlorinated test water.

   Exposure time: 3x3 days, every 3 days change of test water

   Test water quality: Desalinated water, for Cl_2 dem. with 0.6-0.7 ppm free chlorine

   Surface/volume ratio: Migration test - 1:1 cm^2/cm^3
   Cl_2 demand test (depends on range of use)

3. Additional requirements on special compounds to be migrated depending on material composition (for example, aromatic amines from epoxy resins, phenols from phenolic resins, lead from Pb-stabilized PVC pipes, etc.).

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[1] Derived from recommendations given by the German Federal Health Bureau, Berlin.

TABLE 8

MAXIMUM VALUES TO BE ALLOWED IN KTW RECOMMENDATIONS DEPENDING ON RANGE OF USE

RANGE OF USE	ORGANOLEPTICS (TASTE, ODOR, COLOR)	TOC mgC/m^2d	CHLORINE DEMAND $mgCl_2/m^2d$
A: Distribution pipes	Not affected S/V ratio 1:1 cm^2/cm^3	2.5	2.0
B: Reservoirs	Not affected S/V ratio 1:4 cm^2/cm^3	10	8
C: Fittings, Armatures	Not affected S/V ratio 1:6 cm^2/cm^3	15	12
D1: Gaskets with a lot of surface in contact with water	Not affected S/V ratio 1:25 cm^2/cm^3	63	75*
D2: Gaskets with little surface in contact with water	Not affected S/V ratio 1:50 cm^2/cm^3	125	150*

*In 1985, these values will change to 50 and 100.

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REPORT: PANEL NO. 1

JOINING ALTERNATIVES FOR COPPER PIPE

Chairman:	Rhodes Trussell James M. Montgomery Consulting Engineers, Inc. Pasadena, California
Recorder:	Peter Karalekas EPA, Region I Boston, Massachusetts
Panelists:	A.C. Kireta Copper Development Association, Inc. Merrimack, New Hampshire
	Richard Ballentine Silver Institute Cincinnati, Ohio
	Vince Doyle Plumbing and Air Conditioning Contractors of Arizona Phoenix, Arizona
	John Courchene Seattle Water Department Seattle, Washington
	Jerome F. Smith Lead Industries Association, Inc. New York, New York
	Bill Hampshire Tin Research Institute, Inc. Columbus, Ohio
	Allen Hammer Virginia Bureau of Water Supply Engineering Richmond, Virginia
EPA Resource Person:	Marvin Gardels Water Supply Research Cincinnati, Ohio

CHARGES TO PANEL

The panel was charged with four major items for deliberation. They were:

1. to assess extent of water quality impacts from lead/tin solder;
2. to determine if there are acceptable alternatives to lead/tin solder;
3. to determine if there are mitigating steps which may be taken to reduce contamination;
4. to consider other remedial actions that could be taken by government agencies, water utilities, and plumbing and various other private groups.

To accomplish its work the panel was balanced in composition to include a water quality consultant as chairman, four representatives of solder and plumbing material suppliers (copper, silver, lead and tin), an expert in plumbing, a municipal water quality engineer, a state water supply engineer, and an EPA resource person who was expert in corrosion research. In addition there were 18 attendees representing a range of industrial, water utility, academic, and public interest groups and state and federal government agencies.

DISCUSSION

After a review of the panel charge by Chairman Trussell, the seven panelists spoke briefly in turn on various subjects related to the panel charges. A.C. Kireta of the Copper Development Association (CDA) felt that any problem was confined to soft acidic waters. In a CDA study of 142 buildings in Connecticut ranging in age from zero to 120 years old, only two had lead concentrations greater than the maximum contaminant level (MCL) for lead. Mr. Kireta recommended that all new plumbing systems be flushed before being placed in service and questioned present sampling methods for lead in tap water. Among the alternatives to lead/tin solder is tin/silver, which Kireta felt was a good alternative. Brazing of pipe was not desirable because of the many fittings now being manufactured with plastic internal parts which would not withstand high brazing temperatures. Tin/antimony is also an acceptable alternative; however, its use on potable water lines would be difficult to enforce because of the problem of switching by plumbers who would have lead/tin on hand for waste piping. Kireta felt that water treatment to reduce corrosion was the major solution to solving any existing water quality problems.

Richard Ballentine, representing the Silver Institute, pointed out that 95-5 tin/antimony was not a good wetting solder whereas tin/silver was very good and had a higher strength. He estimated that the cost for plumbing a house with tin/silver solder was only $5 to $10 more than tin/lead because of reduced labor costs and the need for less solder due to shorter overlap in couplings.

Vince Doyle, of the Plumbing and Air Conditioning Contractors of Arizona, felt that the solution to the problem with lead/tin solder was to upgrade training procedures for plumbers. He showed examples of poorly soldered joints with excessive flux and solder on the interior of the pipe as well as perfectly soldered joints with only a very thin line of solder exposed to water. Mr. Doyle felt there would be no problem if all joints were soldered efficiently. He also felt that tin/antimony was more difficult to work with.

John Courchene, of the Seattle Water Department, discussed the corrosion problems that had occurred in Seattle. Studies had shown that 60 percent of water samples had exceeded the MCL for iron and 13 percent for lead. Among the problems associated with corrosion were high plumbing repair bills ($7.5 million/year), staining, and health. The solution developed for Seattle involved raising the pH of water from 6.8 to 8.3, encouraging the use of noncorrosive materials such as plastic, and banning the use of solder containing lead. These measures have resulted in the reduction of lead, copper, cadmium, zinc, and iron in Seattle water.

Jerome Smith, Lead Industries Association, conceded that high lead concentrations could be found in the first sample drawn from a faucet in the morning. However, he questioned the meaning of the sample and urged that epidemiological studies be done to determine if lead/tin solder had any effect on blood lead levels. Among the solutions recommended by Smith were treating water to reduce its corrosivity, chemical flushing of all newly plumbed water lines, and the use of preforms in the joints of copper tubing to prevent solder from flowing into the pipe itself which would result in its retention in the joint.

Bill Hampshire, Tin Research Institute, pointed out that lead from soldered joints in tin cans and from gasoline had been reduced significantly. In studies by the Tin Research Institute there are a number of solders that can replace tin/lead. Among the more promising are a tin/copper solder which is weaker than lead/tin but still strong enough for its intended use; other solders under development are stronger.

Allen Hammer, Virginia State Health Department, said that some communities still had lead service lines and that lead had been found there in excess of 10 times the MCL. He described a situation occurring in June 1983 in a house where 18 of 31 samples were greater than the MCL. The piping was removed and replaced using tin/antimony solder. Further sampling found no samples containing lead greater than the MCL. In another house, the highest lead concentration found was 6.1 mg/l before flushing the water. Hammer felt there was no predictability of lead results. Among the actions taken by Virginia were a news release recommending flushing of water lines before consumption, appointment of a task force on building code changes, and further study of the problem. In preliminary results of this new study 11 of 65 samples had lead greater than the MCL, with ranges from 0.001 to 0.4 mg/l lead in waters that ranged from pH 6.0 to 9.1. In another study by a private lab only 1 of 105 samples contained lead greater than the MCL.

In the discussion period following the presentations by panel members, a number of questions and issues were raised. Opinions differed, from one individual who felt there was no problem to others who advocated a total ban on solder containing lead.

A total ban would deal with any future problems, but a number of individuals pointed out the necessity of dealing with the current problem. It was suggested that water utilities be required to treat their water to reduce its corrosivity toward plumbing. The observation was made that there is no standardized technique for sampling for lead. Regarding the issue of the occurrence of the problem being confined to soft water areas, Schock pointed out that in studies in Illinois, the problem of lead was identified in communities with very hard, high-pH water, indicating a more widespread problem. Regarding the ability of manufacturers to meet the demand if lead/tin solder were banned, one individual felt that the marketplace would meet any demand that developed.

FINDINGS AND CONCLUSIONS

1. Lead is present in some waters due to corrosion of solder. The problem has occurred in both hard and soft water areas.

2. New installations, which also may contain particles of lead solder and flux, and supplies with soft, acidic water, may be the worst-case situations.

3. Alternative joining materials such as tin/silver or tin/antimony solder are available should lead/tin solder be displaced.

4. Water treatment methods are available to reduce the problem in certain areas. Also, properly soldered joints, chemical flushing, and preforms may be useful in reducing lead in drinking water.

5. Proper plumbing practice achieved through communication with plumbing groups and training can have a role in reducing the problem.

RECOMMENDATIONS

Although a number of recommendations were put forth by various panel members and the audience, it was generally felt a consensus was reached on the following areas.

1. More study is needed on the presence of lead from corrosion of solder in a variety of water qualities.

2. A standardized sample collection method should be developed to be used in these studies and in monitoring of public water supply systems.

3. Additional studies are needed on treatment techniques to reduce corrosion of lead from solder since simple pH adjustment may not be appropriate for all waters.

REPORT: PANEL NO. 2

METAL PIPE AND FITTING ALTERNATIVES FOR PLUMBING

Chairman: J. Edward Singley
James M. Montgomery
Consulting Engineers, Inc.
Gainesville, Florida

Recorder: Frank A. Bell, Jr.
Office of Drinking Water
Washington, D.C.

Panelists: James R. Boates
Boston Plumbing Company
Natick, Massachusetts

Dodd S. Carr
International Lead Zinc
Research Organization, Inc.
New York, New York

Anthony Colucci
Colucci and Associates
Morgan Hill, California

Larry Galowin
National Bureau of Standards
Washington, D.C.

Joe Glicker
Bureau of Water Works
Portland, Oregon

Stanley Mruk
Plastic Pipe Institute
New York, New York

Robert A. Wilson
Copper Development Association
Purcellville, Virginia

CHARGES TO PANEL

Charges to the panel were to assess the extent of water quality impacts from metal plumbing pipe and fittings and to consider mitigating steps such as water quality control, use of alternative grounding electrodes, limitation or control of some materials, and possible standards and certification programs. Possible training and educational materials development or teaching programs were also to be considered.

To accomplish its charges the panel was balanced in composition and included a water quality/corrosion expert as chairman with discussants including industrial representatives in the areas of copper, galvanized steel, and plastic materials and metal fittings; a plumbing contractor; a municipal water quality engineer; and a government researcher in plumbing systems. In addition there were 15 attendees from a range of industrial, consulting, and municipal and state government sources.

DISCUSSION

Metal pipe and fitting alternatives were outlined by the discussants; key points were as follows:

- Copper pipe is the dominant household plumbing material with principally esthetic effects from copper leaching and staining.

- Galvanized steel pipe has had a level rate of use in the United States and is commonly used in many communities. Leaching effects are principally esthetic with elevated zinc levels, although traces of lead and cadmium may be present.

- Lead pipe and fittings are seldom used except in Chicago where the plumbing code requires that service lines be lead pipe. (See "Lead Product Utilization Survey of Public Water Supply Distribution Systems throughout the United States," April 1984, which is included as Appendix A to this panel report.) Lead levels are elevated in water standing in lead pipes, more so in low-pH, low-alkalinity waters but also in a variety of other waters.

- Metal fittings may also serve as a source of leached contamination, for example lead, where the subject material is contained in the fitting.

Water quality control was urged as the main solution to control corrosion in all types of metal pipe by the metal industry representatives. In general they urged that local utilities provide corrosion control treatment and that decisions regarding piping materials be made at the local level on a case-by-case basis.

On the other hand the water utility representative said that plumbing materials, where identified as the source of contaminants, should be controlled by plumbing code modification. He also discussed the utilization of EPA's Drinking Water Advisory #73 in pursuit of appropriate corrosion control sampling and inquired what national results had been found from the 1980 corrosion monitoring regulations. While not a part of this panel discussion, attention was frequently turned to the subject of lead/tin solder. An undercurrent of concern regarding recent and ongoing moves to ban lead/tin solder was evident through the whole panel session.

A lack of communication was cited by the plumbing representative, who was unaware of the water quality impacts of plumbing materials. He emphatically stated that plumbers wanted to safely and efficiently transmit drinking water to the consumer in the same quality received from the public utility, but he was unaware of some of the problems that had been mentioned.

Other needs for research and development were highlighted in the areas of:

- standardized sampling and analytical procedures for the study of leached contamination.
- improved means of studying corrosion scientifically and efficiently.
- the problem of corrosion from grounding and stray electric current and the effective use of dielectric or separating fittings between dissimilar materials.

FINDINGS AND CONCLUSIONS

While this was a stimulating panel session, the divergent and conflicting views and time limitations prevented a full coverage of all subjects. For the subjects covered, the chief conclusion appeared to be that lead pipe contributes some lead contamination even in waters considered noncorrosive; its use in new plumbing installations has been abandoned in nearly all jurisdictions; there is no logical requirement for its use to continue. The majority conclusion was that its future use should be discouraged or banned.

Panel consensus was evident on the general subject of communication. It was agreed that more formal communication on plumbing materials and water quality needs to be provided, particularly to the plumbing and code development and enforcement communities.

Regarding other materials or problems, there was insufficient information or time to cover the assigned subjects. The questions at hand were important and should be covered in subsequent meetings in more depth.

APPENDIX TO PANEL SESSION 2.

LEAD PRODUCT USE SURVEY OF PUBLIC WATER SUPPLY DISTRIBUTION SYSTEMS THROUGHOUT THE UNITED STATES

INTRODUCTION AND SUMMARY

A survey was conducted by each of the 10 EPA Regional Water Supply Branches to assess the extent of lead utilization in water distribution systems throughout the United States. A total of 153 public water systems, selected from 41 states, including the District of Columbia and Puerto Rico, were examined.

In a previous survey that was conducted almost 60 years ago ("Action of Water on Service Pipes" by Wellington Donaldson, Journal AWWA, 11:649 (1924), 48 percent of the 539 cities that were evaluated had utilized lead service pipes. The results of the present survey confirm that lead products still exist in many water distribution systems and that the utilization of such products in the past was widespread.

With regard to lead in drinking water, many studies show that lead is seldom found in measurable concentrations in water sources. Lead, however, is found frequently in corrosive tap water. Corrosive water may be reduced by a number of measures, such as adjusting the pH, etc.

The problem of corrosion of lead has become such an important issue that the EPA has proposed interim regulations requiring the determination of the presence of specific materials in water distribution systems and monitoring for characteristics of corrosivity of the water. Furthermore, recent studies have indicated lead-tin solder can impart excessive lead concentrations to drinking water.

ACKNOWLEDGEMENT

This survey was prepared and reviewed by David Chin and Peter Karalekas of the U.S. EPA Region I Water Supply Branch staff. Special thanks go to Terry Regan for performing the tedious task of typing this survey. Region I would like to commend the efforts of Water Supply Branch members from the other nine regions who contributed the data and information for this survey and to thank Frank Bell for his encouragement and assistance.

METHODOLOGY

The survey consisted of conducting telephone interviews or sending out the questionnaires to state counterparts or to the particular water systems. Most of the systems that were surveyed represented those that served large populations (91 out of the 153 systems served populations exceeding 100,000 people).

The main problem with this survey was the reliability of the responses that were obtained. A number of questions that were asked involved making rough estimates of the use of lead products in water distribution systems. In some of the systems that we evaluated, recordkeeping just did not exist in the past. Some water system operators or superintendents were more experienced and knowledgeable than others, which in turn resulted in more reliable estimates. Also, some superintendents may just be more cooperative than others, and would be willing to divulge more information and make an effort to do some research. It is difficult to take into account a number of these subjective factors.

In order to obtain uniform response from each of the ten regions, the following questionnaire was developed and suggested to be utilized in this survey:

- What is the total population served by the water system?
- What is the total number of services in the water system?
- What service line materials are being used for new installations?
- What part of the service line does the water system own?
- Were lead or lead-lined service pipes ever installed in the distribution system? If so, how many still remain in the distribution system and where are they located?
- Were lead gooseneck service connections ever used? If so, how many still remain in the distribution system and where are they located?
- Were lead sweatjoints ever used? If so, how many still remain in the distribution system and where are they located? Are they still being used?
- What other service line materials have been used in the past?
- Does the water system have an ongoing replacement program for lead materials utilized in the distribution system?
- Has the system had any problems with high lead concentrations in the distribution system?
- What is the pH of the water in the distribution system? Has the pH been adjusted higher to prevent corrosion problems?

OBSERVATIONS

We primarily focused our attention on the information obtained on the water systems' utilization of lead services, lead goosenecks and lead sweatjoints. The following table summarizes our findings:

Type of Response	# of Systems That Had Utilized Lead Services (Out of 153 Responses)	# of Systems That Had Used Lead Goosenecks (Out of 152 Responses)
Affirmative	112 (73.2%)	94 (61.8%)
Unknown	5 (3.3%)	15 (9.9%)
None Known	36 (23.5%)	43 (28.3%)
Not Asked or No Response	—	1

Approximately 73 percent of the systems we surveyed indicated that lead service lines had been installed in the past. In fact, the City of Chicago still installs lead services for those locations utilizing a size pipe of under and including 2". Lead services are still part of the accepted plumbing code in Chicago.

Lead goosenecks have also been widely used. Nearly 62 percent of the water systems had utilized lead goosenecks. Approximately half of the water systems questioned reported the use of lead sweatjoint in their systems. It is assumed that, because of the universal use of lead-tin solder for joining copper pipes, lead in solder would be found in all of the systems surveyed.

As for the responses regarding the ownership of the service line, they varied widely from the water supplier owning the service line from the main to the meter, property line, or curb, to the consumer owning the entire service line. The significance of these responses is that for many water systems, water suppliers have no responsibility over the utilization of lead products in the home plumbing area.

Few water suppliers have active ongoing replacement programs for any lead materials that have been installed in the distribution system. It appears that water suppliers will only replace a lead service line or a lead gooseneck, for example, when a leak exists.

Many system reported pH values of less than the optimum for controlling lead corrosion. Yet, nearly all of the responses we received on the question of whether there is a problem with high lead concentrations in the distribution system were negative. Once-per-year monitoring for lead required by the NIPDWR would certainly account for many of the negative responses.

We have summarized, alphabetically by state, the information that was submitted from all of the ten EPA Regions in the following table.

Name of Utility and/or Public Water Supply Location	Estimated # of people served	Total # of services	Service line material used for old installations	Service line material used for new installations	Use of lead services % or # still left	Use of lead goosenecks % or # still left	Use of lead sweatjoints % or # still left	pH in the distribution system and if adjusted
Birmingham, Alabama	650,000	150,000	galvanized iron, PVC	copper	none known	none known	none known	8.5 lime added
Montgomery, Alabama	175,000	54,232	galvanized iron, lead	copper	# unknown, replaced if found	none known	Yes, all have been replaced	8.9 lime added
Fayetteville, Arkansas	45,000	11,765	galvanized iron	copper, PVC	none known, replaced if found	none known	Yes, 3-4%	7.5 no adjustment
Fort Smith, Arkansas	71,629	29,000	copper, galvinized iron	copper, PVC, polyethylene	# unknown, general area known	Yes, # unknown	Yes, # unknown	7.5 no adjustment
Hot Springs, Arkansas	43,000	17,700	PVC, copper, galvanized	copper	Yes, none remain	Yes, < 200	none known	8.2 no adjustment
Pine Bluff, Arkansas	60,000	20,077	copper, PVC	PVC	unknown	unknown	unknown	7.1 no adjustment
El Centro, California	26,402	6,100	copper, lead	copper	300	unknown	unknown	7.4 - 7.6
San Diego, California	929,000	208,946	lead used until 1940	plastic, copper	10,000	10,000	10,000	7.6 - 8.2
Arvada, Colorado	86,409	24,500	copper, galvanized	PVC	Yes, # unknown	Yes, # unknown	# unknown, still being used	7.4 adjusted
Aurora, Colorado	187,000	45,000	polyethylene	copper	almost all have been replaced	Yes, 12	none known	7.5 no adjustment
Denver, Colorado	1,000,000	225,000	copper	copper	Yes, # unknown	Yes, # unknown	Yes, # unknown	7.2 - 7.8 adjustment at one plant

Name of Utility or Public Water Supply	Estimated # of people served	Total # of services	Service line material used for old installations	Service line material used for new installations	Use of lead services % or # still left	Use of lead goosenecks % or # still left	Use of lead sweatjoints % or # still left	pH in the distribution system and if adjusted
Bridgeport Hydraulic Co., Bridgeport, CT	336,185	90,000	brass, galvanized iron	PVC, copper	1%	2%	still being used for services	6.8 - 7.5
Hartford MDC, Hartford, CT	391,000	87,000	N/A	copper, brass	none known	Yes, # unknown	Yes 1500	7.01
New Britain Water Department New Britain, CT	99,302	15,802	N/A	copper	Yes, # unknown	1,500	still in use	8.2 - 8.3
New Haven Water Department New Haven, CT	371,259	90,000	brass, lead, galvinized iron	copper, PVC ductile iron	most have been removed	30,000	N/A	7.2
Stamford Water Company Stamford, CT	84,000	19,714	brass, lead, galvinized iron	copper	24	532	N/A	6.7 - 7.1
Waterbury Water Department Waterbury, CT	124,000	25,000	N/A	copper, ductile iron	none known	Yes 10,000	N/A	7.2
Dover Water Department Dover, Delaware	27,500	7,428	N/A	copper	none known	50%	N/A	8.0 - 8.2
Artesian Water Co. Newark, Delaware	140,000	36,449	N/A	copper, PVC	none known	4%	N/A	7.3 - 7.7
Newark Water Department Newark, Delaware	30,000	6,800	N/A	copper	none known	none known	N/A	6.7 - 7.2
Wilmington Water Department Wilmington, DE	140,000	34,252	N/A	copper	<5%	none known	N/A	7.0 - 7.7
Wilmington, DE Suburban Water Co. of Claymont, DE	75,000	23,000	N/A	polyethylene	<1%	<1%	N/A	7.1 - 7.9
District of Columbia	756,500	120,000	N/A	copper	60,000	none known	N/A	7.6 - 8.3

Name of Utility or Public Water Supply	Estimated # of people served	Total # of services	Service line material used for old installations	Service line material used for new installations	Use of lead services % or # still left	Use of lead goosenecks % or # still left	Use of lead sweatjoints % or # still left	pH in the distribution system and if adjusted
Orlando, Florida	300,000	76,100	galvanized, copper	PVC, copper	Yes, all have been replaced	none known	none known	7.8 no adjustment
Tallahassee, Florida	100,000	42,000	galvanized, PVC, lead	PVC, copper	# unknown, some being replaced	# unknown, some being replaced	none known	8.1 adjusted with caustic soda
Atlanta, Georgia	650,000	127,636	galvanized, PVC	copper	# unknown	none known	none known	7.3 phosphate and lime added
Savannah, Georgia	150,000	45,000	cast iron, steel	polyethylene or polybutylene	Yes, # unknown	Yes, # unknown	none known	7.0 - 7.3 no adjustment
Boise, Idaho	105,000	38,482	code accepted	code accepted	100 known	100 known	Yes 4,350	7.1 - 7.7
Cour d'Arlene, Idaho	21,000	9,000	galvinized iron, copper, kalmain	polyethylene, PVC	none known	200	none found	7.0 - 7.2
Idaho Falls, Idaho	41,000	15,600	code accepted	code accepted	none known	10,000	20,000	7.2 - 7.3
Lewiston, Idaho	17,000	4,900	code accepted	copper	# unknown, very early use	not known	# unknown, very early use	7.4 - 7.6 adjusted
Twin Falls, Idaho	26,000	9,489	galvanized	plastic, code accepted	none known	Yes, # unknown	none	7.9 adjusted
Chicago, Illinois (city proper only)	3,000,000	400,000	ductile iron, lead	lead for 2" & under;ductile iron for >2"	all pipe 2" and under remain	For all pipe 2" and under	?	8.1 - 8.5 adjusted
Decatur, Illinois	94,000	31,000	lead, galvinized iron	copper	<100 replaced when found	<100 replaced when found	?	9.5
Gary - Hobart Water Corp. Gary, Indiana	100,000 (Gary Only)	30,000	lead until 1950, copper	copper	25,000 replaced when found	25,000 replaced when found	?	7.6

Name of Utility or Public Water Supply	Estimated # of people served	Total # of services	Service line material used for old installations	Service line material used for new installations	Use of lead services % or # still left	Use of lead goosenecks % or # still left	Use of lead sweatjoints % or # still left	pH in the distribution system and if adjusted
Des Moines, Iowa Water Works	253,078	68,301	galvanized, lead	copper, ductile iron	Yes, # unknown	Yes, # unknown	Yes, # unknown	9.3
Dubuque, Iowa Water Works	62,321	20,390	lead used prior to 1928	copper, ductile iron	5,000	not known	Yes, # unknown	9.5 - 9.6
Sioux City, Iowa Utilities Dept.	82,000	25,000	N/A	copper, PVC, ductile and cast iron	12,000	Yes, # unknown	2,000	7.2 - 7.5
Kansas City, Kansas Board of Public Utilities	160,000	56,000	galvanized	copper, PVC	a few, # unknown	several hundred	several hundred	7.8 - 8.1
Johnson County, Kansas Water District #1	205,000	65,972	galvanized and cast iron	copper	none known	none known	none known	9.0
Topeka, Kansas Water Department	140,000	45,000	galvanized wrought iron	copper, ductile iron, brass	135	none known	none known	9.2 - 9.5
Wichita, Kansas Dept. of Water and Water Poll. Control	280,000	115,000	lead prior to early 1940's	PVC, copper	<15,000 older parts of city	100	none known	8.2
Lexington, Kentucky	290,000	70,000	galvanized, lead, copper PVC	PVC	# unknown, replacement program	# unknown, replacement program	none known	7.2 phosphate and lime added
Louisville, Kentucky	670,000 - 720,000	202,000	galvanized	copper	Yes, # unknown	none known	none known	8.2, lime added
Portland, Maine Water District	141,240	38,000	galvanized iron	copper, ductile iron	none known	200	N/A	6.6 - 6.7
Annapolis, Maryland DPW	95,000	75,000	N/A	N/A	none known	none known	N/A	8.7
Baltimore, Maryland	1,100,000	368,000	N/A	N/A	<0.1%	<0.1%	N/A	7.8

Name of Utility or Public Water Supply	Estimated # of people served	Total # of services	Service line material used for old installations	Service line material used for new installations	Use of lead services % or # still left	Use of lead goosenecks % or # still left	Use of lead sweatjoints % or # still left	pH in the distribution system and if adjusted
Cumberland, Maryland	40,000	17,200	N/A	N/A	none known	none known	N/A	7.4
Hagerstown, Maryland	70,000	16,892	N/A	N/A	none known	none known	N/A	7.5
Washington Suburban Sanitary Commission Maryland	1,705,000	N/A	N/A	N/A	none known	none known	N/A	7.7
Boston, MA Water and Sewer Commission	600,000	90,000	cast iron, Lead	copper, ductile iron, cement-lined	50%	50%	N/A	8.8
Brockton, MA Water Department	89,040	21,455	N/A	copper	none known	<10% 2,000	N/A	9.6 - 9.8
Cambridge, MA Water Department	100,361	13,250	N/A	copper	<10%	<10%	N/A	8.6 - 8.8
Fall River, MA Water Department	100,000	15,500	N/A	PVC, copper	10%	10	N/A	8.5
Lawrence, MA Water Department	62,000	12,000	N/A	copper	1500	none known	N/A	8.0
Lowell, MA Water Department	94,000	18,000	lead, copper, tin alloy	copper	<25% 4,500	<25% 4,500	N/A	7.2 - 7.3
Lynn, MA Water Department	80,000	17,800	copper, lead, cement-lined, galvinized	copper	20% 3,500	40% 7,000	N/A	6.5 - 7.5
New Bedford, MA Water Department	100,169	22,000	N/A	copper	30% 6,600	30% 6,600	N/A	7.0
Newton, MA Water Department	91,066	25,612	N/A	copper, PVC, galvanized, cement-lined	1,000	4,000 - 5,000	N/A	8.8

Name of Utility or Public Water Supply	Estimated # of people served	Total # of services	Service line material used for old installations	Service line material used for new installations	Use of lead services % or # still left	Use of lead goosenecks % or # still left	Use of lead sweatjoints % or # still left	pH in the distribution system and if adjusted
Quincy, MA Water Department	91,200	21,000	N/A	copper	<200	Yes, # unknown	N/A	8.8
Somerville, MA Water Department	80,600	14,000	N/A	copper	<20% 100-200 replaced/yr	Yes, # unknown	N/A	8.8
Springfield, MA Water Department	241,500	43,381	galvanized iron	copper	none known	unknown	N/A	6.8
Worcester, MA Water Department	172,342	37,000	N/A	copper, ductile iron	unknown	unknown	N/A	6.5 - 6.6
Kalamazoo, Michigan	130,000	35,000	lead	copper	5%	5%	?	7.0 no adjustment
Rochester, Minnesota	60,000	17,500	lead, copper, galvanized	copper	30%	30%	?	7.4 no adjustment
Jackson, Mississippi	210,000	66,000	PVC, galvanized	copper, brass	Yes, all have been replaced	Yes, all have been replaced	none known	8.9 - 9.0 lime added
Meridian, Mississippi	49,000	16,000	galvanized	copper	Yes, # unknown	none known	none known	8.5 lime added
Cape Girardeau, Missouri Mo. Utilities Co.	35,000	12,332	galvanized	polyethylene, copper	Yes, none remain	unknown	none known	8.3
Columbia, Missouri, Water and Light Department	62,000	17,000	plastic	copper	# unknown, old section of town	# unknown, old section of town	none known	8.5
Florissant, Missouri Water Department	70,000	15,000	N/A	copper, brass, ductile and cast iron	50	none known	not in use since 1944, may still exist	9.6 - 9.8
Independence, Missouri Mo. Water Company	120,000	40,000	galvanized	copper, ductile iron	very few exist	2,000	none known	9.8

Name of Utility or Public Water Supply	Estimated # of people served	Total # of services	Service line material used for old installations	Service line material used for new installations	Use of lead services % or # still left	Use of lead goosenecks % or # still left	Use of lead sweatjoints % or # still left	pH in the distribution system and if adjusted
Jefferson City, Missouri, Capital City Water Company	33,000	9,300	galvanized, cast iron	copper	Yes, # unknown	Yes, # unknown	Yes, # unknown	9.7 - 9.9
Joplin, Missouri Water Works Co.	55,000	17,000	copper, cast iron, tubeloy	polyethylene tubing	1,500	none known	none known	7.5
Kirkwood, Missouri Water Department	27,987	9,761	galvanized iron	copper	Yes, # unknown	Yes, # unknown	none known	10.0
Lee's Summit, Missouri Water Company	38,000	10,500	galvanized	copper	30-40 %	unknown	Yes, # unknown	7.8 - 8.3
Raytown, Missouri Water Company	15,000	6,500	galvanized	copper	none known	Very few, if any	Very few, if any	9.9
St. Joseph, Missouri Water Company	91,518	30,213	iron tubeloy, plastic, A-C, lead	PVC, copper	8779	8779	17,558	7.6
St. Louis, Missouri Water Division	455,000	118,500	galvanized	copper, ductile iron	unknown as to number & location	Yes, # unknown	still being used	8.4 - 10.2
St. Louis County, Missouri Water Company	1,000,000	260,910	cast iron, galvanized, A-C	copper, PVC, ductile iron	28,000	Yes, # unknown	Yes, # unknown	9.6 - 9.8
Sedalia, Missouri Water Department	22,000	8,833	galvanized	copper, ductile and cast iron	Yes, # unknown	Yes, # unknown	Yes, # unknown	8.0 - 8.4
Grand Island, Nebraska Utilities Dept.	33,944	10,739	cast and ductile iron	copper	2,000	none known	none known	7.3
Lincoln, Nebraska Water Department	174,560	52,488	galvanized, cast iron	copper, ductile iron	innumerable	innumerable	innumerable	7.5
Omaha, Nebraska Utilities District	431,000	126,234	galvanized iron, tube alloy	copper, brass, ductile iron	25,000 - 30,000	25,000 - 30,000	wiped-lead joints	9.0

Name of Utility or Public Water Supply	Estimated # of people served	Total # of services	Service line material used for old installations	Service line material used for new installations	Use of lead services % or # still left	Use of lead goosenecks % or # still left	Use of lead sweatjoints % or # still left	pH in the distribution system and if adjusted
Manchester, New Hampshire Water Works	100,000	22,000	galvanized iron	copper	none known	250	none known	6.6 - 7.8
Albuquerque, New Mexico	342,000	104,400	galvanized	polystyrene, copper, cast iron	1,000 locations known	none known	none known	8.1 No adjustment
Sante Fe, New Mexico	50,000	14,000	galvanized	cast or ductile iron, copper <2"	none known	1,000 locations known	several miles of old lines	7.8 adjusted
Elizabethtown, New Jersey Water Company	500,000	150,080	N/A	PVC for <2", copper, ductile iron	<5% very few	<1% very few	N/A	6.8 - 7.6
Hackensack, New Jersey Water Company	800,000	180,709	N/A	copper for <2", ductile iron	<5% 150 replaced/yr	25,000 100 replaced/yr	N/A	7.8
Monmouth, NJ Consolidated Water Company	249,000	70,121	N/A	copper, PVC, ductile iron	2,972	unknown	N/A	7.5 - 7.8
Newark, New Jersey Water Department	380,000	58,000	N/A	copper, brass, ductile iron	about 75%	none known	N/A	7.5 - 7.9
Passaic Valley, New Jersey Water Commission	287,316	63,000	N/A	copper, ductile iron	about 25%	unknown	N/A	7.1 - 7.3
Buffalo, New York Division of Water	358,000	90,000	N/A	copper, ductile iron, PVC	# unknown	some	N/A	7.5 - 7.8
Erie, County, New York Water Authority	317,000	99,148	N/A	copper, ductile iron, PVC	# unknown	some	N/A	7.8
Jamaica, New York Water Supply Co.	650,000	118,000	N/A	copper, ductile iron	# unknown, many	# unknown, many	N/A	6.0 - 6.9
New York City, New York Aquaduct System	7,071,000	820,000	N/A	copper, brass ductile and cast iron	# unknown, many	# unknown, many	N/A	6.3 - 7.4

Name of Utility or Public Water Supply	Estimated # of people served	Total # of services	Service line material used for old installations	Service line material used for new installations	Use of lead services % or # still left	Use of lead goosenecks % or # still left	Use of lead sweatjoints % or # still left	pH in the distribution system and if adjusted
Suffolk County, New York Water Authority	850,000	246,898	N/A	copper, ductile iron	<1%	none known	N/A	6.7-7.2
Charlotte, North Carolina	350,000	106,342	galvanized, black iron, PVC	copper	Yes, all have been replaced	Yes, all have been replaced	none known	9.3 lime added
Raleigh, North Carolina	165,000	47,000	galvanized iron	copper, brass	none known	Yes, all have been replaced	none known	7.2 NaOH & phosphate added
Bismarck, North Dakota	35,000	8,881	cast iron	copper, plastic	none known	none known	none known	9.3
Fargo, North Dakota	61,281	25,159	iron, lead, copper	copper	Yes 2,500	# unknown, used a long time ago	Yes, 2,500	9.0 - 9.5 lime added
Grand Forks, North Dakota	53,060	8,927	black iron	copper	Yes 2,000	none known	Yes, 4,000	8.6 - 9.2 lime added
Lawton, Oklahoma	100,000	40,000	galvanized	copper	Yes, 250 remain in older areas	Yes, 150 remain in older areas	none known	7.6
Oklahoma City, Oklahoma	460,000	165,000	N/A	copper	Very few remain in older areas	Yes, in old sections of town	Yes, in old sections of town	10.5
Tulsa, Oklahoma	420,000	140,000	galvanized, copper, PVC	copper, plastic, brass, cast iron	Yes, very few remain	Yes, very few remain	none known	7.5
Corvallis, Oregon	43,000	12,000	galvanized	3/4" meter uses 1"copper or plastic	none known	Yes, all known removed	none known	N/A
Eugene, Oregon	103,000	34,777	polyethylene, copper, polybutylene	Copper	Yes, # unknown	Yes, # unknown	Yes	7.2 - 7.3 adjusted
Hillsboro, Oregon	35,000	10,000	galvanized, copper, polybutylene	code accepted	none known	none known	none known	6.9 adjusted

Name of Utility or Public Water Supply	Estimated # of people served	Total # of services	Service line material used for old installations	Service line material used for new installations	Use of lead services % or # still left	Use of lead goosenecks % or # still left	Use of lead sweatjoints % or # still left	pH in the distribution system and if adjusted
Portland, Oregon	650,000	120,000	galvanized	copper is used up to the meter	Yes, # unknown	Yes, 10,000	Yes 20,000	6.8 No adjustment
Salem, Oregon	120,000	45,000	code accepted	code accepted	unknown	none found	some, # unknown, still in use	low 6's No adjustment
Erie, Pennsylvania Bureau of Water	205,000	52,000	copper, galvanized iron	Type k copper	none known	2% remain from 1920's service area	used until early 1960's	7.3 - 7.6
Philadelphia, Pennsylvania Water Department	1,685,000	522,000	copper, galvanized & black iron	copper	Yes, # unknown	Yes, # unknown	leadite joints used; most replaced	7.0 - 8.5
Philadelphia, PA Suburban Water Company	902,000	287,000	N/A	copper	<200	none known	N/A	7.0 - 7.6
Pittsburgh, Pennsylvania Water Department	424,000	89,000	copper	copper	30%	none known	Yes, 5% remain	7.6 - 7.8
Western Pennsylvania Water Company of Pittsburgh, PA	500,000	126,512	galvanized, cast and wrought iron	copper and ductile iron	Yes 5,318	Yes, # unknown	Yes, # unknown	7.1
Metropolitano A San Juan, Puerto Rico	711,999	178,000	N/A	copper, PVC, ductile iron	none known	none known	N/A	7.4 - 8.2
Enrique Ortega La Plata, Puerto Rico	363,936	90,984	N/A	copper, PVC, ductile iron	none known	none known	N/A	7.4 - 8.0
Ponce Urbano, Puerto Rico	241,540	60,385	N/A	copper, PVC, ductile iron	none known	none known	N/A	7.4 - 8.0
Aqua Dilla, Puerto Rico	114,497	28,624	N/A	copper, PVC, ductile iron	none known	none known	N/A	7.8 - 8.2
Caquas, Puerto Rico	109,236	27,309	N/A	copper, PVC, ductile iron	none known	none known	N/A	7.2 - 7.6

Name of Utility or Public Water Supply	Estimated # of people served	Total # of services	Service line material used for old installations	Service line material used for new installations	Use of lead services % or # still left	Use of lead goosenecks % or # still left	Use of lead sweatjoints % or # still left	pH in the distribution system and if adjusted
Pawtucket, Rhode Island Water Department	108,750	21,000	brass, galvanized & cast iron	copper	lead-lined 10% 2,100	none known	N/A	7.2 - 7.3
Providence, Rhode Island Water Department	283,816	69,121	N/A	copper and ductile iron	25%	unknown	N/A	10.0
Warwick, Rhode Island Water Department	78,500	26,000	N/A	copper	100	none known	N/A	10.0
Charleston, South Carolina	350,000	60,000	galvanized steel	copper	Yes, # unknown	Yes, # unknown	Yes, # unknown	8.0 - 8.3
Columbia, South Carolina	231,700	70,440	galvanized	Type k copper	none known	none known	none known	6.9 adjusted
Huron, South Dakota Water Department	13,000	3,500-4,000	lead and galvanized	copper	Yes, # & location unknown	possibly, # & location unknown	possibly, # & location unknown	8.8 - 9.2 adjusted
Pierre, South Dakota	11,973	3,800	ductile and cast iron	PVC	Yes # unknown little used	Possibly, # & location unknown	Possibly, # & location unknown	7.5 - 8.2 no adjustment
Sioux Falls, South Dakota	81,343	25,000	galvanized	copper	Yes, # & location unknown	Yes, # & location unknown	Yes, # & location unknown	7.0 - 8.0 no adjustment
Memphis, Tennessee	800,000	221,709	PVC, galvanized	copper	Yes, some remain in older areas	none known	none known	7.2 phosphate added
Nashville, Tennessee	350,000	105,000	cast iron, galvanized, PVC	copper	# unknown, in old parts of the city	none known	Yes, # unknown	7.8 - 8.0 caustic soda added
Logan, Utah	28,000	56,000	galvanized and ductile iron	copper with brass/bronze fittings	Yes, a little used	Yes, a lot used	Yes, some used with goosenecks	N/A
Odgen, Utah	64,000	20,000	N/A	copper	none known	Yes, many years ago # unknown	none to curb; many inside bldgs	7.1 - 7.2

Name of Utility or Public Water Supply	Estimated # of people served	Total # of services	Service line material used for old installations	Service line material used for new installations	Use of lead services % or # still left	Use of lead goosenecks % or # still left	Use of lead sweatjoints % or # still left	pH in the distribution system and if adjusted
Provo, Utah	75,000	15,000	galvanized	copper	Yes, a few remain	unknown	none known	8.4 - 8.5
Arlington County, Virginia	165,000	34,000	N/A	copper	200	3,000	N/A	8.0
Fairfax County, Virginia Water Authority	650,000	134,000	N/A	copper	none known	none known	N/A	7.0+
Henrico County, Virginia	170,000	48,200	N/A	plastic, copper	none known	1%	N/A	7.3 - 7.9
Newport News, Virginia	333,000	90,000	N/A	copper	<2%	<2%	N/A	7.1
Norfolk, Virginia	270,000	61,700	N/A	PVC	3%	N/A	N/A	7.2
Richmond, Virginia	225,000	62,500	N/A	copper	25,000	none known	N/A	7.2 - 7.6
Bellingham, Washington	50,000	17,000	galvanized	copper or plastic	not known	Yes	Yes	6.8 - 6.9 adjusted
Everett, Washington	300,000	90,000	galvanized and copper	anything Code allows	believed most has been removed	probably	none known	7.4 Adjusted
Seattle, Washington	1,115,000	168,371	galvanized, copper, plastic, kalmain	Code Accepted	Yes, # unknown	unknown	probably	8.00 soda ash and lime added
Spokane, Washington	180,000	62,000	copper, galvanized	Type F copper galvanized,	If used all have been replaced	If used all have been replaced	may have	7.8 none
Tacoma, Washington	214,000	68,362	galvanized, copper	plastic, galvanized copper	none known	none known	Yes, a lot still in use	6.8 - 7.2

REPORT: PANEL NO. 3

PLASTIC PIPE AND FITTINGS

Chairman:	Gary Englund Minnesota Division of Environmental Health Minneapolis, Minnesota
Recorder:	Harry Von Huben EPA, Region V Chicago, Illinois
Panelists:	Alan J. Olson B.F. Goodrich Co. Cleveland, Ohio
	David Spath California State Department of Health Berkeley, California
	Tom Adams Adams, Broadwell and Russell San Mateo, California
	Nina McClelland National Sanitation Foundation Ann Arbor, Michigan
	Ray Lee American Water Works Service Co., Inc. Hadden Heights, New Jersey
	Daniel W. Hurley Associated Lead, Inc. Philadelphia, Pennsylvania
EPA Resource Persons	Ray Jones EPA, Region X Seattle, Washington
	Koge Suto EPA, Region III Philadelphia, Pennsylvania

CHARGES TO PANEL

The panel was charged with assessing the extent of impact to drinking water quality due to leaching from plastic pipe, permeation of plastic pipe, and leaching from joining compounds and solvents; further charges were to assess possible responses to the leaching and permeation problems. Other approaches to the issue of public health and the use of plastic pipe were also considered.

To accomplish its work the panel was balanced in composition to include a state water supply engineer as chairman; representatives of various industrial (plastics and metals), plumbing, and third-party standards interests; water utility and State health engineers; and two knowledgeable EPA technologists as resource persons. In addition there were 23 attendees representing a range of water utility, industrial, research, and state and federal governmental interests.

Charge No. 1: Assess the extent of impact to drinking water quality due to leaching from various types of plastic pipe (PVC, CPVC, PB, etc.).

Discussion

(Discussion on this item was strictly limited to leaching from the pipe itself, with the problems of joining materials considered as a separate issue.)

The argument was made by the plastic pipe interests that plastic pipe has been used and tested for over 20 years with no indication of adverse health effects due to leaching. The point was also made that plastic pipe is regularly tested by the National Sanitation Foundation (NSF) with no adverse health risk being noted.

The counter was made that the report being prepared by SRI International may indicate significant leaching problems. The point was also made that NSF works only from established health limits. The example was given that if chloroform at 99 g/l was found in a sample of pipe, it would be "approved" by NSF -- yet, most authorities would agree that the level should be lower if possible. It was also noted that NSF carefully looks at the analysis of the pipe material, but does not necessarily try to determine other materials that may be present due to the manufacture of the pipe.

Although everyone, more or less, had to concede that additional adverse health effects due to pipe material leaching could be found in the future, the plastic pipe interests were reluctant to endorse a general statement that more research should be done on possible leaching problems.

Panel Opinion

Majority opinion: The majority did not feel there is a problem of adverse water quality due to leaching from plastic pipe, based on known health effects information.

Minority opinion: The minority felt that there is a potential problem and more information and research is needed. They particularly felt there is a greater potential problem with some types of plastic pipe than with others.

Charge No. 2: Assess the extent of impact to drinking water quality due to permeation of plastic pipe.

Discussion

The point was made by plastic industry interests that a great amount of plastic pipe is in use and, percentage-wise, the instances of detection of permeation are extremely small. It was also stated that most authorities will agree that it is not good practice to install any pipe in contaminated soil. Neither of these points were contested.

But, the counter point was made that most pipe is installed when the soil is "clean," with the expectation that it will remain clean for many years, and then, in some instances, the soil becomes contaminated later, creating a problem if the pipe is permeable.

Plastic industry interests stated that they do not deny there is a permeation problem. They said they want to "get a handle on the problem" and "want to be the first to make recommendations on specific areas where plastic pipe should not be used." They also stated that they are looking at protection measures that possibly could be incorporated into manufacture or added during the installation of the pipe.

The point was made that a number of jurisdictions at a local level had already taken steps to control locations where permeable pipe may be used.

Panel Opinion

It was unanimously agreed that there is a demonstrated susceptibility of plastic pipe to permeation by organic chemicals. However, it was recognized that the susceptibility is somewhat variable for different types of plastic.

Charge No. 3: Assess the extent of impact to drinking water quality due to leaching from joining compounds, solvents and other materials.

Discussion

There was general agreement that there is some degree of leaching of compounds and solvents used in pipe joining. There appears to be little information at present on the degree and duration of the problem.

There were opposing views on whether the leaching poses a potential public health risk. One faction stated that there is no data demonstrating a health risk, that the amount of leached material is, over all, very small, and that the problem only persists for a few years after the pipe is installed. Others felt that the exposure is significant enough to seriously investigate the potential health danger.

There was also discussion on the potential of greater-than-necessary leaching of joining compounds due to what is perceived as widespread use of incorrect or "multi-purpose" joining compounds. According to plastic industry representatives, multi-purpose compounds should be used only when pipes of different types are joined; otherwise, only the material specified for the particular type of pipe should be used.

Panel Opinion

Majority opinion: The majority agreed there is a problem of leaching from joining compounds and more information is needed on the health risks that this creates.

Minority opinion: The minority felt there is some leaching that takes place from joining compounds, but that it is not of public health significance.

Charge No. 4: Assess possible responses to leaching problems from piping, joining compounds, and other materials:

- Limit the use of some materials.
- Improve installation techniques.
- Strengthen third-party standards and monitoring programs.
- No change.

Discussion

It was generally agreed that, although there is concern, we are nowhere near considering prohibiting the use of any materials for general use. It was also mentioned that any "limiting" of use in the future might be in regard to ingredients, rather than particular products.

The fact that California and various local jurisdictions have already imposed some regulation on use demonstrates that there is a definite need to strengthen third-party standards and model codes.

Panel Opinion

There was agreement that there is a definite need to strengthen third-party agreements and monitoring to review state, local, and model codes and to continue to review and improve installation techniques. There is a continuing need, as an industry, to review the compounds and solvents used in the manufacture and installation of the products. There is also a definite need for improved information, communications, and instruction from the manufacturers, regulators and trade groups.

Charge No. 5: Assess possible responses to the problems of permeation and water quality:

- Limit the use of plastic pipe.
- Develop new non-permeable pipe materials.
- No change.

Discussion

It was generally agreed that there is a need to notify users and the public that plastic pipe should not be used in contaminated soil.

There was considerable interest in the California regulation prohibiting use of plastic pipe under conditions considered to pose a possible adverse health effect. The regulation is not well known or well enforced, and it was written several years before permeation problems were understood, but it is of interest as a start in recognizing and addressing the problem.

It was agreed that there is a great need for the plastic pipe industry, trade groups, the plumbing industry, and others to bring about an awareness of the impacts of possible permeation.

The plastic industry representatives stated that they are working on development of non-permeable pipe materials. There are also new technologies being developed for improved installation (including soil barriers), preventing migration, etc., that might also be applicable in preventing permeation of plastic pipe.

It was unanimously agreed that "no change" in addressing the problems of permeation was not appropriate.

Panel Opinion

It was agreed that:

- There are areas where there is a need to limit the use of plastic pipe because of existing or potential ground or environmental contamination.
- There is a need for the industry or other bodies to inform potential users of plastic pipe of the limitations of the products.
- There is a need for further investigation into the development of non-permeable pipe or other means of preventing pipe permeation.

Charge No. 6: Detail any other approaches to coping with problems relating to public health and use of plastic pipe.

Discussion

It was again discussed that there is a definite need to positively identify the various types of pipe material and joining compounds or solvents, so that only "compatible" materials will be used. Color coding or other means could be used. This would make it easier for the user to determine what products are appropriate and it would make it much easier for the field inspector to assure that correct materials are being used.

It was stated that NSF is doing some testing for leaching and permeation, and indications are that this program will be expedited in view of the remarks and discussions at this meeting.

There is a great need for the manufacturers and trade associations to "get the word out" to the users and installers on any problems, special conditions of use, etc.

It was suggested that possibly a clause could be incorporated into the NSF or other certification, stating that use of incorrect joining compounds would nullify the certification.

Panel Opinion

It was agreed that:

- There is a need for better communications between the industry, the trades, and consumers and installers on potential problems and/or locations where plastic pipe should not be used.
- There appears to be a need for better identification (color coding, labeling) of plastic pipe and joining compounds/solvents to better assure the use of the proper joining material for each type of pipe.

- "Universal" solvents are supposed to be used only for joining different types of pipe, but are apparently being indiscriminately and generally used due to incomplete information furnished by the suppliers, or because the trades feel they are the easiest to use.

Charge No. 7: What are the indicated desirable or recommended remedial actions by governmental, manufacturing, trade, code, or testing groups?

Discussion

There was unanimous agreement that there has not been adequate communications from any of the groups regarding the plastic pipe problems that have been discussed at this meeting.

It was also discussed that there is a real need for additional testing and research, particularly in regard to "real-world" conditions of installation as they may differ from laboratory-controlled conditions.

There was also mention of a need for consistency in the information put out by the various interested groups. It was also stated that it is often difficult for someone with problems to find a source of information. A "hotline" number for plastic pipe would be very helpful in this regard.

The matter was also discussed, without resolution, that there is a need for each of the interested groups to be doing something specific toward investigating the problems that have been discussed.

Panel Opinion

It was agreed that there is a need to improve communications between all of the interested groups to get consistency in the information being generated.

OTHER PANEL OBSERVATIONS AND RECOMMENDATIONS

A representative of the cast-iron pipe industry stated that gaskets are available for cast-iron pipe that are used when the pipe is to convey organic compounds, so the same material should be usable to prevent contamination of water in the pipe if the soil is contaminated. It seems that this is an important point if permeation of regular gaskets is considered to be a problem, and should be made readily available to the trade and public.

Although it was not specifically discussed by the panel, it should be recognized that the "problems" of plastic pipe actually sort out into three different "jurisdictional" areas:

1. The water mains and water services, generally to the service stop, are usually of a material approved by and installed in a manner specified by the water utility.

2. Some jurisdictions allow the installation of other material past curb stop, so the material could be different. The problems of permeation through pipe is primarily a problem with these jurisdictions.

3. The third problem the panel felt may be significant is from joining material or solvents. This is primarily a problem of interior piping, which is under the jurisdiction and inspection (if any) by the local building inspector.

Somehow, it will be necessary to communicate with each of these jurisdictions regarding the problems that will affect them.

REPORT: PANEL NO. 4

REGULATORY AND COMPLIANCE ASPECTS

Chairman:	Raymond Jarema Connecticut Department of Health Services Hartford, Connecticut
Recorder:	Charles D. Larson EPA, Region I Boston, Massachusetts
Panelists:	James Sargent Wisconsin Bureau of Plumbing Sun Prairie, Wisconsin
	Richard B. Howell, III Delaware Bureau of Environmental Health Dover, Delaware
	Donald Dickerson Dickerson Associates Van Nuys, California
	Charles Buescher, Jr. Continental Water Co. St. Louis, Missouri
	Hugh F. Hanson Consumers/Pirnie Utility Services Co. White Plains, New York
EPA Resource Persons:	Peter Lassovszky and Arthur Perler Office of Drinking Water Washington, DC

CHARGES TO PANEL

The charges to the panel were:

1. Examine the means by which materials/contamination problems can be controlled through Maximum Contaminant Level (MCL) and

monitoring requirements (either existing or as potentially modified) of the Primary Drinking Water Regulations, as regards:

- Lead pipe and fittings.
- Copper pipe, joints, and fittings.
- Galvanized pipe and fittings.
- Plastic pipe, joining compounds, and fittings.

2. Examine the means by which materials/contamination problems can be controlled through:
    - State and local building or plumbing codes.
    - Regional or national model codes.
3. Examine monitoring aspects of code compliance. (For example, how would compliance with a code/solder requirement be monitored?)
4. Examine other mechanisms for regulatory or compliance change.
5. Assess any indicated desirable or recommended remedial actions by:
    - Federal and state drinking water agencies relating to changes in drinking water regulations, monitoring, and implementation.
    - Regional or national model code groups.
    - Local and state code groups.

To accomplish its work the panel was balanced in composition to include a state water supply engineer as chairman, a state code official, two engineers knowledgeable in water utility operations, a former chairman of a national model code development committee, a state water supply engineer involved in changing his state's plumbing code, and two EPA resource persons who are knowledgeable in corrosion and additive aspects. In addition there were 20 attendees representing a range of water utility, industry, research and state and federal governmental interests.

DISCUSSION

Panel members as well as most of the attendees of this panel session felt the approach to solving regulatory and compliance problems must be multifaceted. Limiting the toxic elements in materials used for plumbing as well as treating water to reduce corrosiveness are both essential. Because of the short time allotted for the panel to come up with recommendations, the best approach appeared to be to define responsibilities and assign those responsibilities to the most appropriate organizational entities.

The U.S. Environmental Protection Agency (EPA) was assigned the responsibility of defining the problem, assessing or compiling existing data on a regional or national basis, developing primarily MCLs, and monitoring requirements to regulate corrosion byproducts. It was also thought that EPA should be responsible for preparing source documents for the states. It was recommended that the EPA conduct a national sampling survey similar to the National Organics Reconnaissance Survey (NORS) or National Organics Monitoring Survey (NOMS) surveys. Before undertaking the survey there should be a standardization of sampling techniques and a study designed which would incorporate uniformity in sampling. It was also considered very critical that educational materials for states and local government authorities should be developed by EPA. Water Supply Guidance No. 73 (WSG 73) was passed out to those attending the panel discussion. WSG 73 specifically deals with monitoring and sampling techniques to be used for evaluating the effects of corrosion. There was concern voiced that WSG 73 was not and had not been distributed widely enough and it should certainly be made available to utilities. Also WSG 73 may serve as the basis of a standardized sampling program. A copy of WSG 73 is included as Appendix A to this panel report.

The state's responsibility was defined as being the enforcement agent over the water purveyor. It was also felt that a model code should be developed at the state level. However, there was some debate over whether the model code should be at the state or at the federal level. There was some consensus among the group that communication was necessary to improve state agency interaction and coordination. This interaction includes water purveyors, health departments, and building and housing departments at the state level.

The water purveyor's responsibility was defined as the provision of safe drinking water to its consumers. Water safety is assured through a regular monitoring program; therefore, it is the water purveyor who will be collecting the data in a uniform manner. It is the water purveyor who implements treatment to reduce corrosivity. It is also the water purveyor's responsibility to transmit educational material on an ongoing basis to the consumer, thereby helping to educate the public.

Manufacturers of materials, including materials used to make pipe and joints, should reassess standards on an ongoing basis. Third-party review, for example by the National Sanitation Foundation, was discussed as being a fairly good mechanism for a central standard-setting process.

At the local government level, the consensus was that the responsibility for enforcement of plumbing as well as building code requirements should be administered at this level. Because the inspection and approval process takes place at this level, enforcement should also be administered at this level.

Consumers also have responsibilities and they should use the educational materials distributed to them. The consumer-water purveyor relationship is an essential one that must have credibility and trust incorporated into it.

A building owner's responsibility is to comply with existing codes, standards, and regulations that pertain to his facilities, including building, plumbing, and health codes. Building owners have an ultimate responsibility to their clients in meeting compliance requirements by ensuring that public safety is addressed.

The responsibility for research was not designated, although the general consensus was that additional epidemiological and health effects research is needed.

In summary, communication and public education must be immediately developed and implemented. Corrosive water should be made less corrosive, and exposure to toxic compounds in plumbing materials should be reduced as much as possible. EPA should define the corrosion problem and develop primary MCL and monitoring requirements to regulate hazardous corrosion byproducts. EPA should develop a standardized sampling procedure to help identify distribution system corrosion problems. A national survey of corrosion byproducts using the standardized sampling procedure is recommended.

APPENDIX TO PANEL SESSION 4

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

DATE: AUG 4 1982

SUBJECT: Water Supply Guidance Number 73

FROM: Victor J. Kimm, Director
Office of Drinking Water (WH-550)

Victor J Kimm

TO: Water Supply Representatives, Region I-X
Holders of Water Supply Guidance Series

Attached is Water Supply Guidance Number 73 for Monitoring and Sampling Techniques to Determine Corrosion Products, including lead, in water supply distribution systems.

Several Regional Offices have requested clarification and guidance on sampling techniques to be used for compliance monitoring for metals in drinking water, and on the applicability of MCLs to corrosivity and corrosion products in water.

Neither the National Interim Primary Drinking Water Regulations (NIPDWR), nor the Manual for Interim Certification of Laboratories address the issue of sampling techniques for metals. By definition, an MCL is the maximum permissible level of a contaminant in the water delivered to the consumer. Conventional sampling techniques, in which lines are flushed in an effort to provide a sample representative of the water provided by the supplier of water, is usually considered to be appropriate in terms of the MCL definition. The NIPDWR contained minimum requirements for the MCL, monitoring and reporting, with the expectation that States and other authorities would adapt them to meet local needs. In the cases of substances that are primarily introduced into drinking water during transit, it is probable that more extensive site specific monitoring and sampling methods should be chosen by the local or State authority to obtain a better indication of actual human exposure from drinking water.

Paragraph 141.42 of the NIPDWR requires that community water suppliers identify specific materials of construction that are present in their distribution systems. However, additional monitoring requirements were not specified to determine the presence of the corrosion products that are contributed from these materials to the drinking water. Corrosivity of the water is to be determined on the basis of the Langelier Index, and in certain cases, the Aggressive Index. When there is a potential for an MCL to be exceeded, additional actions are obviously warranted.

Although the regulations are not explicit regarding sampling techniques for corrosion products in water, the States obviously have the authority to require specified monitoring in instances where it is felt that the water quality indices are inadequate to determine the corrosive tendency of the water or where regulated contaminants are potentially present. In such instances, the attached guidance produced by the Criteria and Standards Division can provide a practical tool to determine the representative range of specific contaminant levels to which the consumer might be exposed as a result of the interaction of the water and the materials of construction in the distribution system. The sampling techniques described are not federally enforceable, but are intended only as a guidance.

This approach was adopted from the methods that have been successfully used by Region I in dealing with lead contamination resulting from aggressive water in contact with lead pipe and services.

Water Supply Guidance Number 73

Guidance for Monitoring and Sampling Techniques to Determine Corrosion Products, Including Lead, in Water Supply Distribution Systems

Introduction

The presence of contaminants in the water at the consumer's tap is a function of both treated water quality and distribution system factors that can lead to localized contaminant problems. Because the occurrence of corrosion related contaminants in the water distribution system are often localized, random sampling techniques are not always successful in detecting their presence. Thus, the minimum monitoring requirements as prescribed by the NIPDWR in 1975 may not be appropriate in some situations to realistically determine the extent of consumer exposure to contaminants resulting from corrosive water.

The 1980 amendments to the NIPDWR's established a one year corrosivity monitoring program which was intended to cause systems to identify circumstances where corrosion related contamination may occur, and to encourage appropriate corrective actions. Corrosivity measurements required under these regulations are determined indirectly using the indices (see 40 CFR 141.42(c)) which are based on calcium carbonate saturation.

The indices specified in the 1980 amendments generally measure the tendency of the specific water to form a protective calcium carbonate ($CaCO_3$) layer. The index value is dependent on the pH, alkalinity, hardness, total dissolved solids (TDS) and the temperature of the water. Each of these parameters may independently affect the corrosive tendencies of the water so that waters may be corrosive even though the index indicates non-corrosive conditions.

Therefore, it is generally agreed that the indices may only be applicable to determine the corrosive tendencies of the water within narrow pH ranges, and then only if sufficient amounts of calcium and alkalinity are present in the water. These indices do not take into account the use of corrosion inhibiting chemicals such as hexametaphosphate and bimetalic phosphates. Additionally, calcium carbonate stability, as well as other parameters, may change in the distribution system because of retention in distribution reservoirs and rechlorination.

The sampling techniques suggested herein provide a method to monitor and verify the effective corrosivity of the water and the effectiveness of treatment to control corrosion for those instances where the water quality indices are not applicable. For additional details involving the applicability of corrosion indices and monitoring, refer to the Statement of Basis and Purpose for the August 27, 1980, Amendments to the National Interim Drinking Water Regulations.

Purpose

This Guidance provides a suggested protocol for water suppliers who desire to determine if corrosion products are present in those situations where the existing regulations may not provide sufficient specificity. Specifically, the sampling techniques herein can help to determine the range of specific contaminant concentrations which a consumer might experience as a result of the interaction of the water and the materials comprising the water delivery system. In addition, the Guidance provides criteria to determine when additional actions might be appropriate. The Agency realizes that, due to large variations in water quality and distribution materials in any water supply system, implementation of sampling protocol should be done on a case-by-case basis. The protocol below is a suggested model that States and utilities may use in its entirety or in part as determined by specific situations.

Guidance for the Selection of Appropriate Sample Sites

Sample sites for monitoring should be established at locations where the potential for consumer exposure to a specific contaminant would be greatest. For instance, monitoring for lead should be done at sample sites in the distribution system where the presence of lead pipes or service has been verified. The rationale for problem specific site selection as opposed to random sampling, is that corrosive by-products (i.e., lead, zinc, copper and others) are not normally found in distribution waters in high concentrations except where they are being dissolved from piping materials due to corrosion. Table 1 provides information on the type of contaminants associated with various delivery system construction materials. Table 2 contains a suggested ratio of sampling sites to population served. The design of an appropriate sampling regimen also needs to reflect local conditions including hydraulic configuration, water aggressiveness, sampling costs, analytical costs and other factors. In instances where the presence of a material in the distribution is known to be localized, the ratio of sample sites to population served should be adjusted to reflect the portion of the distribution system affected, rather than the whole water supply system. In addition, sections of the distribution system that are served by multiple sources of different water quality should be treated as a separate entity for sampling purposes to account for variations in water quality in the affected portions served by the various sources.

Table 1

Recommendations for Sampling Parameters

The following parameters are suggested for analysis for different types of pipe material:

Pipe Material	Parameter of Interest
Ductile and Cast Iron (Unlined)	Iron
Copper	Copper, Lead from Solder Joints
Lead	Lead
Galvanized Steel	Zinc, Cadmium, Lead, Iron
Copper Alloys	Copper, Zinc, Lead

Note: Asbestos fibers from asbestos cement pipe was not included as a suggested parameter. Monitoring asbestos cement pipe deterioration is best done in the distribution mains rather than by the sampling program suggested in this guidance.

Table 2

Recommended Number of Sampling Sites to be Monitored on a Quarterly Basis for the First Year

Population Served	Number of Sampling Sites
<100	1
101 - 1000	2
1001 - 5000	5
5001 - 10,000	7
>10,001	10

Note: It is expected that localized variables affecting corrosion are more numerous in larger distribution systems that in smaller ones. For this reason, proportionately more sample sites are recommended for larger water systems in order to better account for these variables.

The water purveyor should use discretion in determining the need for monitoring for specific contaminants. Where previous records and experience has indicated that the water is not corrosive to a specific material or that certain piping materials have not been used, the purveyor should modify his sampling and analytical program to reflect that information.

Once the number and type of samples to be analyzed are established, the water supplier can rank the location of points to be sampled using the following suggested order of priority:

1. Locations where corrosion problems are suspected due to consumer complaints or other indications,

2. Buildings with interior plumbing containing specific materials of interest such as lead, galvanized steel, copper, etc.,

3. Service lines containing specific materials of interest such as lead, galvanized steel, copper, etc.,

4. Recently constructed buildings served by the utility, and

5. Several randomly selected control sites throughout the distribution system.

For example, in lead monitoring, a water supplier would sample for lead at locations meeting priority "1" first. If not enough buildings are available with appropriate interior plumbing, he would determine the remaining locations using priority "2", "3", "4" and/or "5". Sample sites to monitor other contaminants such as iron, copper, zinc and cadmium should be established in a similar manner. The suggested order of priority was established on the basis of maximum potential exposure to the consumer. Priorities "1", "2" and "3" are self explanatory. Priority "4" was established on the basis of field data which indicates that corrosion rates are much higher in the newly constructed plumbing than older ones.

There are a number of options available for the utilities to perform a survey to locate and identify specific sample sites. Consultation of records and archives may be one of the best approaches for some larger and older systems to determine the general location and presence of contamination sources. This approach will reduce manpower and time requirements in the field to pinpoint the exact location of the source of contamination. Often, the local or county health department might have already conducted a survey involving health-related contaminants in the water as a result of distribution system corrosion.

An alternative approach is to have utility personnel, such as meter readers or meter repairmen develop information as a routine part of their normal jobs. It is usually possible to determine the type of material used for service lines by checking the connections at the meter. Another method which could be utilized is to mail questionnaires. However, it should be noted that such an approach usually produces poor results, since only a small portion of the customers may reply, and the information provided may not be reliable. The surveys could be conducted by initiating a direct house-to-house search for the identity, type and source of materials in the distribution system. This latter approach would only be attractive for small utilities having few connections.

Guidance for Collection of Samples for Analysis*

To determine the representative range of contaminant levels to which the consumer is exposed during the course of daily activities, the samples should be collected early in the morning. The samples should be drawn from interior faucets to get water that has been in intimate and sustained contact with the interior plumbing, the service line and water main as follows:

Sample 1 - The sample reflecting interior plumbing condition is collected immediately upon opening the faucet. This represents water that usually has been standing in the fixture and interior plumbing for a 6 to 8 hour period.

Sample 2 - The sample reflecting service line condition is collected after the water has been running and the sample collector feels the water temperature change from warm to cold. Since water would be expected to warm slightly after standing in interior plumbing, this cold water represents water that had been standing just outside the foundation of the house in contact with the underground service line for the same 6 to 8 hour period.

Sample 3 - The sample representative of the water main is collected after allowing the water to run for at least three minutes after the initial temperature change was noted. This water would have had a minimum contact time with the service line and interior plumbing and probably represents the ambient distribution water quality. The length and size of pipes in the building should be considered to determine if the 3 minute contact criterion is applicable.

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*Karalekas, P. C., Jr., Ryan, C. R., Larson, C., Taylor, F., "Alternative Methods for Controlling the Corrosion of the Lead Pipe." Paper presented at the Annual Conference of the New England Water Works Association, Boston, Massachusetts, 1977.

This method of sample collection provides an indirect profile of consumer exposure to corrosion related contaminants. Water that has been stationary in the interior plumbing overnight has had maximum contact time with the source of contamination and represents water that may be drunk by the consumer early in the morning. The second sample represents the water that was standing in the service line and may represent water used for preparation of breakfast beverages such as coffee or tea. The third sample, taken after running the water, represents water that is commonly drawn during the same day when water is more frequently used. It is obvious that no single sampling protocol can represent every scenario of exposure. The suggested protocol is an attempt to estimate typical exposure potential. Utilities and States are encouraged to use other protocols if a specific exposure situation can be sampled with more confidence. Further study is required before a more accurate universal protocol can be articulated.

Recommendations for Sampling Frequency and Interpretation of Results

To account for seasonal variations in water quality affecting corrosion, the sampling should be repeated at least quarterly for a period of one year. This sampling frequency may be reduced in instances where the water obtained is solely from the ground and it has been established that the water quality is constant through the year. In reviewing these quarterly samples and in making determinations about corrective action, the water supplier should consider any first draw sample or any average value (average of 3 samples taken at one location) that are greater than the ambient or background levels for the particular contaminant being evaluated. Neither the first draw sample nor the average values of the 3 samples taken at each location would constitute an MCL violation per se, but they would give good indications of the possibility that an MCL is being exceeded for some portion of the time and that a part of the population is being exposed to elevated levels of the corrosion product. It may be that a reassessment of the MCL compliance monitoring regimen should be undertaken to assure that the monitoring program being used is indicative of the quality of water being consumed in those parts of the system that are being affected by corrosive waters.

If the above sampling results show that the highest average concentration from any one set of the four seasonal samples at each sampling point is below MCL values, reducing the frequency of sampling at each site to one sample per year is justified, but this sample should be obtained during the seasonal period that revealed the greatest corrosion induced contamination. If the above sampling survey results show that the average concentration of contaminants from any one set of the four seasonal samples at any sampling point exceeds the MCL (or other level of concern for unregulated contaminants) remedial action should be contemplated. Such actions might include treatment additions or modifications to reduce the corrosivity of the water, the use of corrosion inhibiting chemicals, or changes to piping materials to alleviate the health risk associated with isolated local problem areas. Quarterly sampling should continue until the average concentration of contaminants is known to be consistently below the MCL (or other level of concern for unregulated contaminants.)

A maximum contaminant level is defined to be, "...The maximum permissible level of contaminant in water which is delivered to the free flowing outlet of the ultimate user of a public water system...contaminants added to the water under circumstances controlled by the user, except those resulting from corrosion of piping and plumbing caused by water quality, are excluded from this definition." MCLs have been established for lead and cadmium in the National Interim Primary Drinking Water Regulations, and for copper, zinc and iron in the National Secondary Drinking Water Regulations. These MCLs define the level of contaminant at which corrective actions are appropriate and required. However, the wording of the Safe Drinking Water Act and the legislative history that accompanied the Act direct that any human exposure to potentially harmful contaminants should be minimized to the extent feasible. Concentrations of corrosion by-products such as lead and cadmium can reach levels in excess of the MCL in very short periods of time (40 minutes or less in some studies).* Therefore, even though the average values obtained using the previously discussed sampling protocol or samples taken in accordance with the minimum requirements set out in the National Interim Primary Drinking Water Regulations do not technically exceed the MCL, any elevated contaminant levels indicate the potential for excessive exposures and prudent public health policy would dictate corrective or remedial actions.

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*Peacock, Stuart J., "Factors Influencing Household Water Lead: A British National Survey". Archives of Environmental Health, Vol. 35, No. 1, Jan-Feb 1980, pp. 45-51.

Briton, A., "Factors Influencing Plumbosoluency in Scotland", Journal of the Institution of Water Engineers and Scientists, Vol. 35, July 1981, pp. 350-364.

REPORT: PANEL SESSIONS

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

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BACKGROUND

The panel sessions of the seminar were divided into four subject areas:

1. Joining Alternatives for Copper Pipe
2. Metal Pipe and Fitting Alternatives for Plumbing
3. Plastic Pipe and Fittings
4. Regulatory and Compliance Aspects.

Charges to each panel followed the general framework of assessing the current state of knowledge, identifying problems, assessing alternative solutions, and recommending future steps to cope with the identified problems.

KEY CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations represent a sense of the meeting in the important areas of concern, especially emanating from the panel discussions.

LEAD/TIN SOLDER

Lead is present in drinking waters, both hard and soft, due to corrosion of lead/tin solder. New installations, which also may contain particles of lead solder and flux, and supplies with soft, acidic water may be the worst-case situations.

Several state and local jurisdictions have acted and others are considering acting to ban lead/tin solder from potable water plumbing. There were strong differing opinions and no consensus could be reached regarding the desirability of banning the future use of lead/tin solder. Alternative joining materials such as tin/silver or tin/antimony solder are available should lead/tin solder be replaced.

Water treatment methods are available to reduce the problem in certain areas. Since poor plumbing practice appears to be involved in several incidents of excess potable water lead levels, improvements in plumbing practice through communication and training can have a role in reducing the problem. In addition the use of chemical flushing and preforms may be useful in reducing lead contamination levels.

Recommendations:

a. While the occurrence of high lead levels attributable to lead/tin solder was accepted, it was recommended that more study and analysis of data were required to assess the extent and severity of lead contamination in a variety of water qualities.

b. Additional investigative and research work were also recommended to develop a standardized sampling method and to refine water quality treatment and control measures.

LEAD PIPE AND FITTINGS

The use of lead pipe for potable water has been abandoned by most jurisdictions throughout the United States with the exception of the City of Chicago, where the plumbing code requires that service lines of 2 inches or less in diameter be lead pipe. Lead levels are elevated in water standing in lead pipes, more so in low-pH, low-alkalinity waters but also in a variety of other waters. Since there are economic alternative materials, including copper, galvanized steel, and plastic (currently used in many cities as shown in an EPA survey of April 1984), there is no logical requirement for the continued use of lead pipe and fittings.

Recommendation: The majority recommendation was that the future use of lead pipe and fittings should be discouraged or banned.

TREATMENT OR WATER QUALITY ADJUSTMENT

A basic paper was presented on techniques of water treatment to minimize corrosion. In the panels on joining alternatives for copper pipe and on metal pipe and fittings, a repeated theme emphasized the problems of controlling leaching from existing systems. Corrosive waters will increase the rate of leaching from lead pipes, a residual of which exists in many communities, and from copper pipe joined by lead/tin solder. Excess contaminant leaching has been associated with a variety of water qualities. Since simple pH adjustment may not be appropriate for all waters, more study and research are needed on treatment techniques to reduce corrosion.

Recommendations:

a. All public water utilities should review their water quality and potential corrosion problems and should take steps to make their water quality less corrosive where elevated contaminant levels occur.

b. Additional study and research should be conducted to define the occurrence of corrosion in a spectrum of water qualities and to develop appropriate anticorrosion treatment methods.

MONITORING FOR CORROSION BYPRODUCTS

Several panels pointed out questions with respect to corrosion sampling techniques and the need for developing a standardized approach. When EPA's Water Supply Guidance 73 (WSG 73) was passed out at one panel meeting, concern was expressed that it had not been distributed widely enough and was virtually unknown in many communities. EPA also promulgated corrosion monitoring regulations in 1980 and their results remain to be determined.

EPA was assigned responsibility for defining the corrosion problem and for developing primary Maximum Contaminant Levels (MCLs) and monitoring requirements to regulate corrosion byproducts. The state's responsibility was defined as being the enforcement agent over the water purveyor. The water purveyor's responsibilities were defined to include implementing corrosion monitoring in a uniform manner, adjusting water quality to minimize corrosion, and rendering a safe quality water to consumers.

Recommendations: EPA should define the corrosion problem and develop primary MCL and monitoring requirements to regulate corrosion byproducts. Development of a standardized sampling procedure that would help identify distribution system corrosion problems and a national survey of corrosion byproducts utilizing the standardized sampling procedure are recommended.

PLASTIC PIPE AND FITTINGS/LEACHING

The leaching of toxic substances from plastic pipe to drinking water has been the subject of long-term standards and monitoring under the National Sanitation Foundation (NSF) third-party program. Few problems and no adverse health risk have been noted in over 20 years of surveillance for covered products. However, not all byproducts of plastic manufacture may have been covered in the NSF program: a minority felt the need for further research, particularly with respect to some materials more than others.

Contamination of drinking water from the use of solvents and joining compounds in the field assemblage of some plastic pipes represents a significant concern. There was also discussion on the potential of greater than necessary leaching from the misuse of incorrect or "multipurpose" compounds. The multipurpose compound would be used when two pipes of different materials are joined; otherwise, only the material specified for a particular type of pipe would be used. Apparently a lack of materials identification and incomplete use instructions from suppliers may be responsible for much of the misuse of multipurpose joining compounds.

Recommendations: There was majority agreement that there is a problem of leaching from joining compounds and that more information is needed on the health risks that this creates. Specific recommendations were to strengthen third-party agreements and monitoring; to review state, local, and model codes; and to review and improve installation techniques. The industry was urged to review the compounds and solvents used in the manufacture and installation of plastic products.

PLASTIC PIPE AND FITTINGS/PERMEATION

Research has shown that plastic pipe and fittings are permeable to organic chemicals such as gasoline and trichloroethylene and that drinking water contamination has occurred in several instances where such chemicals have come into contact with plastic pipe. Research has also shown that asbestos/cement pipe and the gaskets used for joining ductile iron pipe are permeable to some organic chemicals.

While the extent of contamination from the permeation of plastic pipe appears to be limited, there was general agreement that it does occur and that plastic pipe should not be used in areas subject to organic chemical contamination. California does have a health department regulation prohibiting the use of plastic pipe under certain conditions considered to pose a possible adverse health effect. Plastic industry representatives stated that they are working on development of nonpermeable pipe materials. There are also new techniques being developed for improved installation, such as soil barriers, that might be helpful in preventing the permeation of plastic pipe.

Recommendations: There were general recommendations that the use of plastic pipe be limited in areas of existing or potential contamination; that industry or other bodies inform potential users regarding limitations of products relating to permeation, and that further investigation should be made into the development of nonpermeable pipe or other means of preventing pipe permeation.

INFORMATION TRANSFER AND COMMUNICATION

From its inception, this seminar represented a first meeting of many varied interests in which government, industry, plumbing experts, etc., took an active part in considering drinking water corrosion contamination problems and possible solutions. A common observation was that insufficient information transfer and dialogue had occurred in the past, particularly between the governmental water supply interests and the industrial and plumbing sectors.

Further, it was felt that insufficient time was available at this seminar and that the subjects covered were too broad to allow adequate time for meaningful discussion and resolution of issues.

Recommendations: There was a general recommendation for more study and deliberation in the substantive areas and for subsequent meetings planned with more focussed discussions and more time allowed. A further recommendation was made for more formal communication such as articles, papers, joint small discussions, etc., on plumbing materials and water quality, so that problems and solutions can be properly communicated among all the varied interests.

SUMMATION - PLUMBING MATERIALS AND DRINKING WATER QUALITY

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The Workshop was opened by Cotruvo, who introduced the subject and gave the themes of the program: to permit the airing of views and to provide directions for the future. Cotruvo suggested that the Workshop focus on three questions:

1. Do problems exist?
2. What technical solutions are available?
3. What are the roles of the various organizations?

I. DO PROBLEMS EXIST?

A. Materials

1. Copper

Anderson reported that copper piping has several good features: it is popular, functions well, has a good program of quality assurance, is based on the eddy current method, and is available during manufacture; also, the industry has developed techniques that remove the drawing chemicals. He noted, however, that copper pipe does give some problems; for instance, pitting can cause leakage, and corrosion will occur if utilities do not treat their water properly. This is particularly true in small utilities, where treatment is less sophisticated.

2. Plastic

Plastics were discussed by Mruk and Podoll, who noted that the favorable features of this material are its immunity to corrosion, the smooth surface of the piping material, the lack of need for soldering joints, and the flexibility of the pipe. Mruk pointed out some unfavorable factors, however, such as problems with jointing materials, the additives in the plastic pipe, its susceptibility to high temperatures, its combustibility, and the reduction in strength as the duration of loading increases. Podoll studied chlorinated polyvinyl chloride (CPVC) pipe and found that a few volatile organic compounds leached out at the 1 to 10-microgram/liter (ug/L) concentration. He also noted that some jointing compounds were found during the leaching test initially, but then were rinsed out. Organo-tin initially leached at a concentration of 0.5 to 3 ug/L, but the concentration fell to 0.1 ug/L after 3 weeks.

3. Lead

None of the speakers or the panelists had many favorable comments to make about lead pipe, but Karalekas reported on severe lead problems in the New England area. He pointed out that even 5.5 percent of running samples exceed the regulated lead concentration. Karalekas discussed his sampling protocol of a standing sample, a short-term running sample, and a long-term running sample; several other speakers and panelists mentioned the importance of standardizing these sampling procedures as they do affect the overall metal concentration in the resulting water sample.

4. Galvanized Pipe

Neff pointed out that new pipe dissolves more zinc into the water than pipe that has been in place for a period of approximately 2 years. Neff also pointed out that chrome-plated brass valves, such as are found in the household, produce metal concentrations in water; he suggested that studies on piping systems should take into account the contribution of metals from the valves and faucets.

5. Solders

Murrell presented data from a study on Long Island, where the authors found that 67.3 percent of the piping systems had solders containing from 55 to 65 percent lead content. They found that this solder leaches metals on standing and that in new homes, very high lead levels were initially found. They also pointed out that slugs of water with high concentrations of lead occurred periodically as water is drawn through a plumbing system. As water that has been in contact with a soldered joint comes out of the tap it will contain leached metals.

B. Penetration Problems

Pfau and Goodwin reported on the penetration of several solvents through jointed and unjointed ductile iron, polyvinyl chloride (PVC), and asbestos/cement (A/C) pipe. When the ground was saturated with solvents only the solid ductile iron pipe resisted penetration. All joints permitted the penetration of solvent into the water and solid A/C pipe passed the solvent quite easily. Solid PVC pipe also passed the solvent, but only after 32 days. Goodwin reported similar data when the pipe was challenged with approximately 300 mg/L of solvent.

C. Importance of Water Chemistry and Environment

Anderson noted that copper pipe would corrode if water velocities are greater than 5 ft/sec, the water has a high concentration of carbon dioxide, and the water is soft. Karalekas reported the impact of soft water and low pH on lead solution. Neff indicated that with galvanized piping, chlorine residual had an influence on metal loss as did low pH, and commented that polyphosphates may aggravate the metal loss situation. Murrell noted that low pH and soft water caused increased problems from soldered joints.

II. WHAT TECHNICAL SOLUTIONS ARE AVAILABLE?

A. Water Treatment

Schock reviewed the impact of pH, carbonate concentrations, orthophosphate, polyphosphate, and silicate on lead, copper, and zinc. Schock pointed out that the solubility of lead actually goes up as the carbonate concentration goes up, a find that might not be intuitively obvious to the unsuspecting. He pointed out that many people use the Langelier Index to calculate calcium carbonate deposition, but that several factors in the Langelier Index are based on rather old data; therefore, the actual pH of saturation is frequently a few tenths of a pH unit different than calculated by the traditional Langelier Index. He also pointed out that polyphosphates are quite different from orthophosphate and that in some cases polyphosphates may actually cause higher metal content in water. Finally, he noted that silicates often produce a favorable effect on galvanized pipe. Karalekas showed several case histories in which the benefits of increasing pH had a dramatic effect on the lead content in New England waters. The importance of proper water treatment was also discussed in the panels.

B. Regulations

Several alternative techniques (other than water treatment) for controlling corrosion byproducts in water were suggested by various speakers. For instance, Murrell recommended that lead solder be banned and alternatives such as silver or tin-antimony be used to avoid the dissolution of metal from the solder. Boydston discussed altering plumbing codes as a way of controlling the resultant water quality in household distribution systems. He also pointed out that, in the absence of Federal regulations, state and local ordinances could be passed to control the use of certain plumbing materials. Wagner thoroughly reviewed European practice, pointing out that many countries in Europe had regulations restricting the use of materials that would have a deleterious effect on water, for instance lead pipes and lead solder. He also pointed out that plastic pipe material was controlled by statute in many European countries. Another approach to control would be Federal regulation by the U.S. EPA. Currently many metals are regulated, either as primary or secondary drinking water regulations and the corrosivity of water should be measured. Vigorous corrective action through enforcement after finding corrosive water would help reduce the insult to the consumer from dissolution of metal. The importance of education as a method of improving the current situation was pointed out by the panels.

C. Third-Party Review

McClelland reported on the extensive review, inspection, and testing protocol of the National Sanitation Foundation (NSF) for plastic pipe. By investigating the manufacturing products that went into pipe and the manufactured product itself, the NSF is able to ensure that pipe containing their seal meets rather rigorous standards. In any manufacturing product quality control is important. Mruk, for example, told of subsequent problems that resulted from a plastic pipe manufactured without a necessary additive.

No matter which approach, or combination of approaches, is used for controlling the deterioration of water quality during passage through distribution piping and plumbing systems, inspection and enforcement is essential to make this system work. For instance, during the Workshop examples were given of plumbers who switch from more desirable to less desirable solders when inspectors are not looking; of water utilities that will not treat water to the degree recommended by the consulting engineer; of pipe that may be sold in an area where it is unsuitable (problems occurred some years ago with asbestos/cement pipe in soft water areas; and of installation practices not properly followed, for example, the kinking of plastic pipe in an effort to have it bend beyond its traditional flexibility.

III. WHAT ARE THE ROLES OF THE VARIOUS ORGANIZATIONS?

All three parties represented at this Workshop have an important interest in this subject. The manufacturers want their products to enjoy a good reputation, both with the public and with the regulators, so they can sell their product. The regulators want to be able to offer users alternative piping materials and they want to protect the health of the public. The independent service groups such as the NSF provide an essential link between the other two parties.

The Workshop was successful in generating a dialogue among the three parties mentioned above. Only through cooperative effort, such as the one demonstrated in this Workshop, can the ultimate goal of safe water for the consumers be realized.

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